

# **Development of rice flour incorporated wheat based low gluten shelf stable kashmiri flat bread**

**Qudsiya Ayaz**  
(2016-666-D)



**Division of Food Science & Technology**

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**Sher-e-Kashmir University of Agricultural Sciences &  
Technology of Kashmir**

**2022**

**Development of rice flour incorporated wheat based low  
gluten shelf stable kashmiri flat bread**

**Qudsiya Ayaz**  
(2016-666-D)



**Thesis**

Submitted to

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in partial fulfillment of requirements for the award of the degree of

**Doctor of Philosophy in Food Technology**

**2022**



*Dedicated*

*To my*

*Beloved Parents*

*&*

*My Daughter*

**Sher-e-Kashmir**  
**University of Agricultural Sciences & Technology of Kashmir**  
**Faculty of Horticulture, Division of Food Science & Technology**

**Certificate – I**

This is to certify that the thesis entitled, “**Development of rice flour incorporated wheat based low gluten shelf stable kashmiri flat bread**” submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy in Food Technology**, to the **Faculty of Horticulture, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir** is a record of bonafide research work carried out by **Ms. Qudsiya Ayaz (Regd. No. 2016-666-D)** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

It is further certified that any help or information received during the course of investigation has duly been acknowledged.

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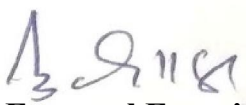
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**ABSTRACT**

A study was conducted at the Division of Food Science and Technology, SKUAST-K to develop low-gluten rice-wheat flat bread. Rice and wheat flour, were evaluated for physicochemical, pasting and farinographical properties. It was observed that wheat flour possessed highest moisture content, protein, crude fibre and crude fat while as highest carbohydrate content was found in rice flour. Pasting properties showed that all of the Rapid-Visco Analyzer (RVA) parameters i.e. Pasting time (sec), Peak viscosity (cp), Hold viscosity (cp), Breakdown viscosity (cp), Set back Viscosity (cp) and Final viscosity (cp) were significantly ( $p < 0.01$ ) higher in rice flour compared to wheat flour.

The processing conditions were further optimized for development of low-gluten flat bread using Central Composite Rotatable Design (CCRD). Response Surface Methodology (RSM) software Design-Expert 12 was used to investigate the effects of processing conditions on characteristics of low-gluten flat bread. The independent variables included the feed composition i.e, rice flour: wheat flour (0:45- 55:100), mixing time (2-10 min), fermentation time (30-70 minutes) and baking temperature (250-300°C). Dependent variables were TPA, bread parameters, Instrumental colour and overall acceptability. Significant ( $p < 0.05$ ) models, having coefficient of determination ( $R^2$ ) in the range of 0.92-0.99 were recorded in the selected dependent variables. Predicted and adjusted  $R^2$  values were in reasonable agreement with each other in all the dependent variables. In all the dependent variables lack of fit was found to be non-significant. The optimized conditions for development of low-gluten flat bread were RF: WF (48:52), mixing time (3.3 min), fermentation time (70 min), and baking temperature of (282°C). The optimized flat bread had significantly higher mineral profile, lightness ( $L^*$ )

and lower hardness in addition to having a better overall acceptability. The optimized rice-wheat flat bread was further incorporated with three hydrocolloids guar gum (GG), carboxymethylcellulose (CMC) and sodium stearoyl lactylate (SSL) at three different concentrations of 0.3%, 0.6% and 0.9% respectively and was studied for quality and storage stability. Texture profile analysis (TPA) and FT-IR studies revealed that bread incorporated with guar gum at 0.6% concentration showed best antistaling properties and retrogradation was reduced profoundly. Also, guar gum incorporated with flat bread at 0.6% concentration received highest score by panelists at 5 point hedonic scale.

Further the hydrocolloid incorporated rice wheat flat bread was packed in metalized polyester (MPE) for a period of 10 days under ambient (20°C,50%RH) and accelerated conditions (38°C,75-80%RH). The results revealed that that ambient conditions and metalized polyester packaging was found most suitable for the packaging and safe storage of guar gum incorporated rice wheat flat bread. From storage studies inference drawn was that developed rice wheat flat bread incorporated with 0.6% guar gum can be stored safely in metallized polyester up to 6 days under ambient conditions.

**Keywords:** Rice flour, wheat flour, low-gluten, flat bread RVA, FT-IR, GG, SSL, CMC, metalized polyester

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## Chapter 1

### INTRODUCTION

Cereal grains have been the principal component of human diet and have played a major role in shaping human civilization for thousands of years. Around the world; rice, wheat and maize, are important staples and critical to daily survival of billions of people. More than 50% of world's daily caloric intake is derived directly from cereal grains consumption (Awika, 2011). Cereals and cereal products are staple foods in most human diets in both developed and developing countries, providing a major proportion of dietary energy and nutrients (Kevith, 2004). They are composed of approximately 75% carbohydrates, mainly starches and about 6–15% protein, contributing in global terms more than 50% of energy supply. The worldwide production of cereals is estimated to be 2791.3 million tonnes (FAO, 2021).

At global level, wheat production amounts to approximately 769.6 million tonnes (FAO, 2021). In India, wheat is the second most important cereal crop and the production is estimated to be 109 million tonnes (FAO, 2021). Wheat (*Triticum aestivum*) is one among the different cereals grown all over the world. It provides substantial nutrients in human diet and brings huge economic benefits to the growers and manufacturers (Shewry and Hey, 2015). Wheat flour has unique functional characteristics in food manufacturing. These characteristics are attributed to mainly two fundamental macromolecular components. Those are protein (gluten), which is responsible for forming dough into bread and starch, which is the main non-structural carbohydrate naturally found in cereal grains. Starch is the major component of wheat kernel as it contributes 54-72% of dry weight. It is packed in endosperm as small microscopic particle which is known as starch granule (Elvers and Ullmann, 2017).

Wheat is the basic raw material for bakery and household food products and needs to be pulverized into fine flour before preparing different end-products.

The quality of flour determines its suitability for a particular product. It is consumed worldwide after milling it into flour (Whole wheat, refined or maida). In India, wheat is one of the daily staples, consumed in different forms of flat breads, such as chapatti, paratha, phulka, tandoori roti and naan. Maida is used extensively in Central Asian and South Asian cuisine. Flatbreads such as Naan and Tandoori roti are made using maida.

In wheat, gluten content is about 12-14%. (Saxena *et al.*, 2000). Gluten is the major factor responsible for causing certain disorders and allergies in some individuals mostly celiac disease. Celiac disease affects approximately 1–2% of general population all over the world. Celiac disease is a chronic immune-mediated enteropathy of the small intestine that develops in genetically susceptible individuals by exposure to gluten proteins found in certain (Scherf *et al.*, 2016). Prevalence of this disease has been rising in many developing countries including India where in 1% of the population from Northern part of the country is affected with gluten intolerance (Hamdani *et al.*, 2020).

Gluten-free technology is used to reformulate a gluten-free version of products especially for people who are unable to digest gluten (Gallagher, 2009). In gluten-free industries, many types of flours can be used to replace wheat flour. Rice flour is the most popular ingredient in the gluten-free products. Rice (*Oryza sativa*) is the most widely cultivated cereal in the world after wheat and is the most important food crop. Rice is the staple food for about half of the world population. Globally, rice production amounts to approximately 504.17 million tonnes (FAO, 2021). Rice production in India is estimated to be at 184.5 million tonnes (FAO, 2021). The biological value of rice protein (B.V=80) is much higher than that of wheat or other cereals. Rice is characterized by low prolamin, hypoallergenic activity, insipid taste, low sodium and high digestible carbohydrate contents, which is suitable to be incorporated into celiac diets. Rice flour is well accepted and one of the most used cereal grain flours for the production of gluten

free products due to its bland taste, white colour, high digestibility and hypoallergenic properties (Marco and Rosell, 2008).

For centuries, baked cereal products have been widely consumed throughout the world according to recipe and culture. Among these bread is a basic dietary item dating back to the Neolithic era and is the most popular because of its nutritional quality and its sensorial and textural properties. Bread is eaten mainly as a chief source of energy and provides as much as 50-90% of total caloric and protein intakes of people in the cities and villages (Khaniki, 2007).

Flat breads are probably the oldest, most diverse and most popular products in the world. It is estimated that over 1.8 billion people consume various type of flat breads in Central America; many parts of Africa, especially North Africa; parts of Southern Europe; the Indian subcontinent; the Middle East; Turkey; the Southern States of the former Soviet Union (Armenia, Georgia, Azarbiajan, Torkamanstan, Uzbekstan and Tajikstan) and many other countries. Flatbreads are very popular type of bread, especially in those parts of the world where bread is consumed as a major source of dietary protein and calories (Mir *et al.*, 2014). It is believed that people have been making flatbreads for more than 6000 years. The world's oldest baking oven was found in Babylon in 4000 BC and records of flatbread baked in the hot ashes or on heated stone slabs in the old kingdom of Egypt in 2500 BC (Kumar, 2016).

The flat breads are usually produced from a simple recipe consisting of flour, yeast, sodium-bicarbonate, salt and water in varying proportions, however, sometimes the manufactures also uses ingredients like fat, sugar, skim milk powder and certain chemicals for improving the bread quality. They could be leavened or unleavened, traditionally the leaving is achieved by sour dough but bakers yeast and sodium bicarbonate are also used (Mondal and Datta, 2008).

The freshness of flat bread is the holistic attribute and is prized for its taste, aroma and texture. Because of the lean formula, they stale quickly during storage

and shelf life is limited to few hours (Sidhu *et al.*, 1997; Swyngedani *et al.*, 1991) resulting from the physiochemical changes that lead to a loss of freshness with an increased firmness and an alteration of its organoleptic quality and becomes difficult to chew which is considered objectionable in acceptance by consumers (Gujral, 2002). The staling of baked goods results in loss in texture, increase in crumb firmness, loss of product freshness and eating quality.

Due to an increasing consumer demand for fresh bread, new technologies have been developed to avoid these undesirable changes and to extend bread shelf life (Fik, 2002). One method involves the addition of particular components, such as emulsifiers, hydrocolloids and enzyme preparations to the recipe (Barcenas, 2003). These, additives such as hydrocolloids, emulsifiers and enzymes have been used to improve the rheological properties of the dough, structural and texture characteristics, as well as the shelf life of gluten-free breads (Demirkesen *et al.*, 2013; Mahmoud *et al.*, 2013).

Another method applied to prevent bread staling consist of modifying the process conditions so as to offer the consumer fresh bread at any time. Hydrocolloids are considered as effective additive in reducing staling (Gujral *et al.* 2004). The ability of hydrocolloids to prevent firming and retrogradation of starch in bread is well known (Martinez *et al.*, 1999 and Rojas *et al.*, 1999) and their abilities to bind water and physically hinder the amylopectin retrogradation (Gujral *et al.*, 2004). Hydrocolloids can retard staling caused by an increase in the retrogradation enthalpy of the amylopectin as in case of frozen stored breads and extends shelf life of baked products via prevention of water loss during baking (Barcenas *et al.*, 2003).

Flat bread can be divided into two major groups according to their cross section: single layered and double layered. They differ in the type of flour, manner of sheeting or in the appearance of the end product (Qarooni *et al.*, 1992). Single layered flat breads locally known as (*Girda* and *Lavasah*) are the main dietary staple of the people in Kashmir Valley. They are generally consumed fresh and

are produced by local bakers under most unhygienic conditions. These flat breads should have a pleasing color and should retain their soft and pliable structure during storage with extended shelf life. (Mir *et al.*, 2014).

Flat breads in Kashmir Division of Jammu and Kashmir are traditionally produced by local semiskilled bakers by mixing maida with water, salt and sodium bicarbonate without weighing the ingredients. Mixing is performed manually and finally baking is done in traditional earthen oven without having any control on time and temperature. The whole process for production of kashmiri single layered flat bread is performed under most unhygienic conditions as the process is completely manual and traditional. Besides the bread gets subjected to retrogradation within one hour of production leading to staling of bread.

In order to make the process commercially available to industries, for production of flat breads hygienically in Kashmir the studies shall be conducted to optimize the process of flat bread preparation through baking technology, to reduce the gluten content in the breads and to increase the shelf life with the following objectives.

1. Optimization of the processing conditions for the development of rice flour incorporated wheat based local flat bread
2. Effect of hydrocolloids on the quality and stability of rice flour incorporated wheat based local flat breads.
3. Effect of packaging material and storage conditions on the quality and stability of flat bread.

## **Chapter-2**

### **REVIEW OF LITERATURE**

The germane literature covering research topic “Development of rice flour incorporated wheat based low gluten shelf stable kashmiri flat bread” have been reviewed under following headings:

- 2.1 Physicochemical characteristics of wheat and rice flour
  - 2.1.1 Proximate composition
  - 2.1.2 Sugar and starch analysis
  - 2.1.3 Mineral profile
  - 2.1.4 Rheological properties
- 2.2 Optimization of processing conditions for development of flat bread.
  - 2.2.1 Physicochemical properties of optimized product
  - 2.2.2 Texture profile analysis
  - 2.2.3 Bread parameters
- 2.3 Effect of hydrocolloids on quality and shelf life stability of optimized flat bread.
  - 2.3.1 Proximate Composition
  - 2.3.2 Texture profile analysis
  - 2.3.3 Bread Parameters
  - 2.3.4 Degree of staling
- 2.4 Storage studies of low gluten optimized flat bread.

## 2.1 Physicochemical characteristics of wheat and rice

### 2.1.1 Proximate composition

Jamal *et al.* (2016) studied the proximate composition of flours obtained from various rice varieties, i.e., Super Basmati Shaheen, Super Basmati Kainat, Super Fine, JP5, Basmati 385, Fakhr-e-Malakand grown in different areas of Pakistan.. Moisture content, ash content, crude protein and crude fat of rice flour ranged from 5.46–7.08%, 0.48–1.23%, 8.02–9.85% and 0.43–1.5%, respectively.

Devi *et al.* (2015) evaluated ninety two rice varieties for estimating proximate composition. Analysis of variance showed significant differences in the proximate compositions of the rice varieties studied. The results indicated high percentage of carbohydrate in all the genotypes (73.6 to 83.7%) and the varieties Bhuban and Prachi had the highest carbohydrate content (83.7%). Sahyadri hybrid showed the highest crude protein (11.0%), while Swarna had the least crude protein (5.9%). Pusa basmati 1 and Swarnamukhi (NLR 145) varieties showed the highest moisture content percentage (11.6%) while Bhuban variety (7.13%) contained the lowest percentage moisture content. MTU 1001 and MSS 5 contained highest fat content (3.7%) while Barah Avarodhi possessed the lowest fat content (0.9%). Crude fibre content was low in majority of the samples. Only two varieties *i.e.*, MTU 3626 and MTU 1010 contained highest crude fibre (0.99%) while Pusa Basmati 1 possessed highest ash content (2.3%). Carbohydrate was significantly and positively correlated with energy and negatively correlated with moisture per cent. The association of moisture per cent with carbohydrate and energy was significant but negative

Mari *et al.* (2018) examined the two varieties of rice flour shadab and shua. The result indicated that highest values in all parameters for pH content, moisture content, ash content, fat content, protein content, fiber and carbohydrate were significant ( $P < 0.05$ ) in shua flour as compared to the shadab flour. The shua chapatti contained highest pH content 6.5, moisture content 12.32, ash content

1.20, fat content 0.96, protein content 2.87, fiber 2.21 and highest carbohydrate 84.33 were recorded respectively. Whereas the results of shadab chapatti contained lowest pH content 5.58, moisture content 11.26, ash content 1.07, fat content 0.75, protein content 2.31, fiber 1.58 and highest carbohydrate 81.55 respectively.

David *et al.* (2015) assessed the proximate composition and selected functional properties of soft wheat flour. The commercially available soft wheat flour was purchased from local suppliers at Kajetia market in Kumasi-Ghana. The flour were cleaned of foreign materials and sieved through 75  $\mu\text{m}$ . The flours were packaged in air-tight plastic containers prior to analyses. The flours were analyzed for their proximate composition. The flour functional properties were determined and compared with those of asomdwee cowpea flour. The results showed that the soft wheat flour had higher (1.33%) fat and carbohydrate content (83.60%) than the cowpea flour. The crude protein, fibre, moisture and ash content were all lower in soft wheat flour as compared to the cowpea flour.

Ahmed *et al.* (2016) studied the influence of incorporating wheat flour (WF) on broken rice flour (BRF) at different concentrations (0, 20, 40, 60, 80 and 100 g/100 g) on the proximate compositions. It was found that per cent protein (8.93–12.25%), ash (0.52–1.01%) and moisture contents (4.47–7.09%) showed significant ( $P < 0.05$ ) increase, while fat content (1.41–1.17%) showed significant ( $P < 0.05$ ) decrease by blending wheat flour with broken rice flour.

Kaushik *et al.* (2014) selected four wheat cultivars, milled and assessed the effectiveness of different drying methods on physicochemical and reconstitution properties of wheat gluten. Gluten was extracted and its wet and dry gluten content were estimated. The washed starch and other flour constituents were dried. Isolated gluten was dried using three treatments *viz.* oven drying, vacuum drying and freeze drying. The dried gluten and washed and dried flour constituents were then reconstituted and this flour was checked for flour quality (SDS volume, texture analysis and falling number). Only reconstituted flour using

freeze dried gluten showed no significant difference to control flour in SDS volume and dough strength. In Falling number, all reconstituted flour samples showed significant difference to control flour. The reconstitution properties were also best for freeze dried gluten.

Saeid *et al.* (2015) analysed the proximate, physicochemical, functional properties of six brand of wheat flour in Bangladesh. The entire brand had moisture contents: 9.90-12.48%, protein: 8.67-12.47%, fat: 0.893-1.387% and ash content: 0.387-0.707%. The ACI brand had the highest amount of protein of 12.47% whereas Romoni brand had highest fat of 1.387%, fiber: 0.26%, gluten content: 15.34% and water absorption index of 1.9 g/g as compared to other brands.

Syed *et al.* (1992) gave a brief review of physical parameters, protein content, gluten content and mineral content of Indian wheat. Huebner and Gaines (1992) reported that hardness was correlated with at least one gliadin fraction and not with the original position of kernels in the ear. They reported that the difference in hardness among single kernels of the cultivars might be due to variation in protein synthesis in kernels located at different positions in kernel head.

Kaushik *et al.* (2014) assessed the effectiveness of different drying methods on physicochemical and reconstitution properties of wheat gluten in four wheat cultivars. Gluten was extracted and its wet and dry gluten content were estimated. The washed starch and other flour constituents were dried. Isolated gluten was dried using three treatments *viz.* oven drying, vacuum drying and freeze drying. The dried gluten and washed and dried flour constituents were then reconstituted and this flour was checked for flour quality (SDS volume, texture analysis and falling number). Only reconstituted flour using freeze dried gluten showed no significant difference to control flour in SDS volume and dough strength. In Falling number all reconstituted flour samples showed significant difference to control flour.

### 2.1.2 Sugar and starch analysis

Murugadass and Dipnaik (2018) evaluated the starches of wheat and rice by isolating them. Amylose and Amylopectin ratio was determined to predict the glycemic index of both. Wheat and rice having the same amylose and amylopectin ratio were selected for our study. These isolated starches were subjected to invitro enzymatic hydrolysis by salivary and pancreatic amylases. Reducing sugars released after hydrolysis and incubation of 0, 5, 10, 15, 20 and 30 minutes were estimated by Folin-Wu method. Statistical analysis was carried out in the form of unpaired student's t-test to find significant difference between means of reducing sugars release by wheat and rice during enzymatic hydrolysis and the results revealed that the rice had low digestibility than the wheat starch. Rice starch releases less amount reducing sugars gradually while the wheat starch releases more reducing sugars rapidly in a short period of time. This can be due to amylopectin A which might be present in larger quantities in wheat starch than in rice starch which assists in rapid digestion of wheat starch.

Chatterjee and Das (2018) studied, the amylose content of the ten rice varieties of Assam. The varieties of polished and unpolished rice selected for this study were namely, Ranjit, Bahadur, TTB-404, Mulagabhuru, Luit, Disang, Joymoti, Kanaklata, Lachit and Chilarai. The amylose content of both the unpolished and polished varieties were found to be lowest i.e.  $6.86 \pm 0.15$  to  $7.93 \pm 1.43$ g/100g. Whereas the highest amylose content in unpolished and polished varieties was found to be highest in Joymoti and Chilarai respectively. All the unpolished and polished varieties were found to be significantly different between the groups but are found to be significantly similar within them.

Gogoi *et al.* (2020) investigated the gluten and amylose content in rice and buckwheat flour for the development of rice based gluten free biscuits. Two varieties of rice, non waxy (Bahadur) and waxy (Aghuni bora) and buckwheat flour were selected to investigate amylase and gluten content by following standard methods for developing a rice based gluten free biscuit which will be

suitable for celiac patient. The results showed Amylose content of waxy rice was found to be 0.81 per cent, non waxy rice was 27.2 per cent and buckwheat flour 25 per cent. Gluten was not detected in any of the flours. Thus, flours which were tested for amylase and gluten content were found to be suitable for making gluten free biscuit by substituting wheat flour with rice flour and the judicious combination of waxy and non waxy rice flour will also be very good to overcome problems of dough handling and binding.

Omar *et al.* (2016) studied the five different types of rice samples of Kurdistan Region Iraq. The starch content of rice samples was found to be in the range of 81.23-92.73%. The high starch content of 92.73% was obtained by sample-5 and the low and standard of starch content of 81.23% was obtained by sample-1. The total sugar content of rice samples was determined by using a phenol-sulfuric acid method at different hydrolysis time under constant acid concentration (2% H<sub>2</sub>SO<sub>4</sub>) and temperature (25°C). The maximum sugar achieved for sample-3 was 19.72% at 20 min, due to sufficient time to hydrolyze and cleave all glycosidic linkage in the rice samples with occurring minimum degradations and the minimum total reduced sugar content of rice samples observed were Sample-4 was 7.93% at 20 min, probably due to insufficient of hydrolysis time or degradations of forming monosaccharides in the presence of hot concentrated acid.

Barak *et al.* (2012) examined the two wheat varieties 'C 306' and 'WH 542'. wheat varieties were milled to obtain flour fractions of different particle sizes. Various physicochemical parameters such as wet and dry gluten, falling number and damaged starch content of the flour fractions were analyzed. The damaged starch values ranged from 5.14% to 14.79% for different flour fractions and increased significantly with decrease in particle size. content. Cookie quality was adversely affected with increase in damaged starch content. It was observed that the effect of the damaged starch content on the cookie quality was variety specific. Thus, damaged starch content could be included in the quality control

analysis as an important criterion for determining the cookie making potential of wheat varieties with greater damaged starch inferring poorer cookies. From the study it was concluded that wheat flour of particle size greater than 150 µm produced cookies with best quality.

### **2.1.3 Mineral Profile**

Zubair *et al.* (2012) studied the minerals profile of selected rice (*Oryza sativa* L.) varieties of Pakistan. Minerals profile as studied by inductively coupled plasma optical emission spectrometry (ICP-OES), showed that the tested varieties of rice mainly contained calcium 825 to 1330 mg/kg, magnesium 960 to 1225 mg/kg, zinc 191 to 319 mg/kg, ferric 186 to 317 mg/kg, copper 13.24 to 16.65 mg/kg, aluminum 59 to 105 mg/kg, manganese 19.25 to 26.10 mg/kg and chromium 10.90 to 24.45 mg/kg. The amounts of sodium and potassium, determined by flame photometrically, were noted to be 89 to 109 mg/kg and 2378 to 2794 mg/kg, respectively

Oko and Ugwu (2011) estimated the mineral element contents of five major rice varieties in Abakaliki, South-Eastern Nigeria. Analysis of variance showed no significant difference ( $p>0.05$ ) in sodium, phosphorous, calcium and magnesium contents and significant difference ( $p<0.05$ ) in nitrogen (Canada> (Awilo, Faro15) >Sipi>Faro14) and potassium (Canada>Sipi>Awilo>Faro15>Faro14) contents of the rice varieties was observed. Canada variety was observed to be superior in phosphorous, calcium and magnesium contents among other varieties studied.

Saeid *et al.* (2015) estimated the mineral composition of six brand of wheat flour in Bangladesh. Sodium and calcium content were higher in ACI brand whereas potassium content was found to be higher in Romoni brand.

Verma and Srivastav (2017) analysed a total of six aromatic and two non-aromatic rice accessions, grown in India, for their nutritional quality attributes including mineral contents. Among the minerals, the higher Ca (98.75 mg/kg), Zn (17.00 mg/kg) and Fe (31.50 mg/kg) were in Gopal Bhog, whereas the highest Na

(68.85 mg/kg) was in Badshah Bhog, the highest K (500.00 mg/kg) was in Swetganga, Khushboo and Sarbati.

#### **2.1.4 Rheological properties:**

Sarker *et al.* (2008) investigated dough characteristics of mixtures of wheat flour and potato starches from three different cultivars (Eniwa, Benimaru and Norin No.1) using a Brabender farinograph. The water absorption of control wheat dough was higher than that for all mixture doughs and decreased significantly with increase in potato starch. The peak time of wheat-flour-potato starch mixtures ranged from 21.0 to 22.5 min, with no large difference with increase of potato starch. Dough stability significantly increased with increase of potato starch. The increase of potato starch in the mixtures decreased the tolerances of mixing, indicating that they were weaker than the control flour. Breakdown time of mixtures tended to be the same as for control wheat flour up to 5% potato starch, above which it increased significantly.

Fari *et al.* (2010) studied the effect of incorporating widely grown popular rice varieties, namely Bg 300, Bg 352, Bg 403, Bg 94-1, Ld 356, Bw 272-6b, At 405 and At 306 in bread making at a level of 30% mixed with wheat flour. Physical dough properties (i.e. water absorption, dough development time, stability, time of breakdown and tolerance index) of composite flour were tested using the Brabender Farinograph. The results revealed that Water absorption value ranged from  $59.67 \pm 0.58$  % in Bg 94-1 to  $61.33 \pm 0.58$  % in Bg 352. Dough development time ranged from  $3.3 \pm 0.3$  min. for Bg 352 to  $7.3 \pm 0.3$  min. for Bw 272-6b. Rice variety Bw 272-6b incorporated blend had the highest stability with  $16.3 \pm 1.3$  min.

Singh *et al.* (1988) in their comparative study of the farinographic characteristics of bread wheat, durum wheat and triticale reported moderate water absorption for the bread wheat cultivars and adjudged their doughs to be best among the three on the basis of various parameters studied.

Varavinit *et al.* (2003) categorized rice cultivars according to amylose content into three groups: low, medium and high amylose content cultivars. The correlation of amylose content with gelatinization properties, retrogradation and pasting properties of eleven cultivars of Thai rice were investigated. Rice flour was prepared from milled rice by the wet grinding process. Onset ( $T_o$ ), peak ( $T_p$ ) and conclusion ( $T_c$ ) temperatures of gelatinization (determined by DSC) were found to be highly positively correlated with amylose levels. This correlation could be used for prediction of amylose content of rice flour. Low amylose starch could also be characterized by low degree of retrogradation (%R). The data obtained from RVA-viscograms (peak viscosity, breakdown, setback and pasting temperature) can be used only for characterization of the group of low amylose starches (waxy rice). It was demonstrated that low amylose rice starch provided the highest peak viscosity and breakdown and the lowest setback and pasting temperature among the groups investigated.

Rithesh *et al.* (2003) characterized the physio-chemical properties of starch in commercially and traditionally cultivated rice varieties using Rapid Viscosity Analyser (RVA) in relation to identify the genotype with prominent starch composition to maximize the consumer's acceptability. Initially a study conducted to determine the amylose content variations among the selected genotypes and measurement on RVA parameters had a significant difference among the varieties. The polished riceflour showed higher range of peak viscosity, hold viscosity, breakdown viscosity, finalviscosity and setback viscosity than brown rice flour. polishing had a major influence on the pasting curve. The rice accessions with similar amylose content differed in all the pasting profile indicating the heating and cooling cycle among the same sample concentration. The combined study of amylose content with RVA profile will provide a better understanding in evaluating the rice cooking and eating quality and RVA based pasting parameters provides a quick selection of quality rice genotypes with mere precision. Correlation among pasting traits showed that the pasting parameters such as peak

viscosity, setback viscosity and pasting temperature was found to be the most substantial variables in determining the amylose content of rice flour.

## **2.2 Optimization of processing conditions for development of product**

Gomez *et al.* (2011) studied the effect of mixing time on two Argentinean commercial flours (FI and FII) for bread making. Both flours showed a similar electrophoresis profile but different content of free sulfhydryls. Rheology of dough obtained from flours (DI and DII) revealed that DI presented a more elastic matrix. FI required more than 8 min for an optimum development of gluten, while DII was already fully developed (development time: 7.3 min). Up to 16 min of mixing, DI matrix maintained the sheet like structure while DII showed a more filamentous one, characteristic of a weak and over kneaded dough. This weakness of gluten network obtained from FII was accompanied by a depolymerization process.

Shittu *et al.* (2007) the effect of baking temperature and time on some physical properties of bread from composite flour made by mixing cassava and wheat flour at ratio of 10:90 (w/w). A central composite rotatable experimental design (CCRD) was used while the baking temperature and time investigated ranged from 190 to 240°C and 20 to 40 min, respectively. Loaf volume, weight and specific volume varied significantly ( $p < 0.001$ ) from 440 to 920 cm<sup>3</sup>, 162 to 183 g and 3.31 to 5.32 cm<sup>3</sup>/g, respectively. The tristimulus color parameters such as L\* (lightness) and brownness index (BI) of the crust varied significantly ( $p < 0.01$ ) from 31 to 72 and 68 to 123, respectively. Due to the complex effect of temperature and time combination, most of the measured properties could not be reliably predicted from the second order response surface regression equations except the loaf weight and crumb moisture.

Das *et al.* (2012) used response surface methodology (RSM) to study the effects of baking conditions on various baking parameters and thus the optimum conditions selected for further studies. Time and temperature are the two

important baking conditions on which the quality and acceptability of the breads depend. They studied that, baking temperature and time were the predictor variables and loaf specific volume, crumb moisture and crumb hardness were the dependent variables (responses). Baking temperature and time ranged from 200 to 240°C and 10 to 30 min respectively. Loaf weight, volume and the color of the crumb and crust of the bread samples varied significantly with the baking time and temperature. Quadratic model fitted with the experimental data of specific volume, crumb moisture and hardness obtained. This study revealed that varying temperature-time combination during baking leads to significant changes in the physical characteristics of coriander fortified wheat breads. All the responses were significantly affected by the varying factors. Bread specific volume, crumb moisture and hardness fitted well with the quadratic model. The baking conditions obtained from optimization were  $220\pm 2^{\circ}\text{C}$  and a baking time of  $20\pm 2$  min. From this optimization, bread loafs having desired loaf weights, volume, crumb softness and crust color were obtained. Thus, the study is useful in interpreting the basic baking conditions of wheat breads fortified with herbal constituents.

Jahromi *et al.* (2013) conducted a systematic study for optimization of final proofing time, FPT (20–60 min), dough mixing time in low speed, MTLs (63 rpm) and in high speed, MTHS (180 rpm) for 2.05–8.05 min based on bread moisture content, water activity, specific volume, sensory quality factor, hardness, dough adhesiveness, cohesiveness, hardness, chewiness, stickiness, resilience features using response surface method was designed. Results indicated that a higher value of quality and sensory features as well as dough cohesiveness was achieved by FPT level. Increasing MTLs led to increase in dough adhesiveness, hardness, chewiness and bread hardness. Correlation results revealed that specific volume may be considered for bread hardness ( $r = -0.75$ ) and dough stickiness ( $r = -0.81$ ) prediction. The suitable mathematical model for staling kinetics was power model. The optimization results were 56.84-min FPT, 2.05-min MTLs and 7.69- min MTHS and are useful for bread quality improvement.

Shah *et al.* (2017) developed maize flat bread supplemented with asparagus bean flour (ABF). Preliminary study was conducted for maximum supplementation of ABF on the basis of sensory attributes and it was found that 15% ABF can be supplemented. Further a composite flour containing 85% maize flour (MF) and 15% ABF was used for the preparation of flat bread. The effect of baking temperature (200 to 235 °C) and baking time [time 1 (surface 1) and time 2 (surface 2)] (70 to 120 sec) on product responses such as sensory characteristics (overall color, appearance, flavor, taste, mouth feel, overall acceptability), texture (shear value) and moisture content were studied. Results indicated that baking temperature and baking time had significant ( $p < 0.05$ ) positive effect on sensory characteristics and shear value, while significant ( $p < 0.05$ ) negative effect on moisture content. The response surface methodology was found to be successful in determining the optimum process conditions for the production of best quality flat bread with desirable properties of all the responses. The processing conditions such as, baking temperature 225 °C, baking time 1 (120 sec) for surface 1 and baking time 2 (116 sec) for surface 2 were recommended for the development of best quality flat bread.

Swami *et al.* (2015). Studied the effect of three different yeast concentrations i.e. 2.0, 2.4 and 2.8% and baking temperatures 230°, 240° and 250°C on baking time (min), hardness of slice (g), volume expansion (%) and whiteness index of bread was observed. These dependent variables were analysed for optimization of bread for nine treatments. Sensory analysis of prepared bread by the various treatments was performed by coding different samples with market sample by using 9 point hedonic scale to get acceptable concentration of bread. Various sensory parameters of the bread were colour, texture, flavour, taste, mouth feel and acceptability was taken into consideration. Most accepted product from the sensory score was sample having yeast concentration 2.8% and baking temperature 240°C. The desirable quality of slice bread was based on the responses i.e. lower baking time, more volume expansion, more whiteness index

and lower hardness. The optimum zone for acceptability of bread was observed at baking time 20-21 min, volume expansion 665-718%, whiteness index 44- 46 and hardness of slice 10.0-10.5 g was observed at yeast concentration was 2.5 to 2.8% and baking temperature was 239.5° to 245.62°C. The quality parameters were correlated with sensory score for acceptability of the sliced bread. The bread can be prepared by using yeast concentration 2.5-2.8% and baking temperature 239.5°-245.62°C for lower baking time, more value of volume expansion, more whiteness index and less hardness of slice.

Flander *et al.* (2007). Studied the baking technology for tasty bread with high whole meal oat content and good texture. Bread was baked with a straight baking process using whole grain oat (51/100 g flour) and white wheat (49/100 g flour). The effects of gluten and water content, dough mixing time, proofing temperature and time and baking conditions on bread quality were investigated using response surface methodology with a central composite design. Response variables measured were specific volume, instrumental crumb hardness and sensory texture, mouthfeel and flavour. The concentration and molecular weight distribution of b-glucan were analysed both from the flours and the bread. Proofing conditions, gluten and water content had a major effect on specific volume and hardness of the oat bread. The sensory crumb properties were mainly affected by ingredients, whereas processing conditions exhibited their main effects on crust properties and richness of the crumb flavour.

### **2.2.1 Physicochemical properties of optimized flat bread.**

Matos and Rosell (2012) characterize diverse gluten-free like breads (GFB) in order to discriminate them and to establish possible correlations among descriptive parameters of GFB features determined by instrumental methods and sensory analysis. Statistical analysis showed that all physical, physicochemical characteristics (specific volume, moisture content, water activity,  $L^*$ ,  $a^*$ ,  $b^*$ , hue and chroma), hydration properties (swelling, water holding capacity and water binding capacity), texture profile analysis parameters (hardness, springiness,

chewiness, cohesiveness and resilience) and structural analysis of the crumbs (number of cells and total area) significantly ( $p < 0.05$ ) discriminated between the GFB types tested. Sensory analysis revealed great divergences in crumb appearance, odour, springiness, crumbliness and color of samples, but no significant differences ( $p > 0.05$ ) in flavour, aftertaste and hardness of them. Certain significant correlations were established within the parameters determined by instrumental methods. Hydration properties of the crumb showed positive correlations with cohesiveness and resilience. Significant correlations, but scientifically meaningless, were observed among the instrumental and sensory parameters, because correlation coefficients were rather low, which represent very weak or low linear correlations ( $r \leq 0.35$ ). The principal component analysis showed that sensory parameters described in this study and also hydration properties besides texture parameters would be suitable for characterizing bread-like gluten free products.

Torbica *et al.* (2012) developed gluten-free cookies based on rice and buckwheat flour in three different ratios, 90/10, 80/20 and 70/30. Physicochemical properties of buckwheat and rice flour as raw materials in gluten-free cookie formulation and its relationship with final product quality were evaluated. Chemical and electrophoretic analyses indicated that gluten-free flours exhibited similar protein/ starch ratio and more narrow protein molecular weight range in comparison to wheat flour. On contrary, mean particle size of rice and buckwheat flour was higher in comparison to wheat flour, while the damage starch content was lower. The gluten-free cookies were prepared at pilot scale and their colour and sensory attributes were compared to wheat-containing sample. Combination of rice as the brightest flour and buckwheat as the darkest has yielded the cookies of non-significant difference in lightness in comparison to wheat cookie. On contrary, gluten-free flours and cookies showed significantly lower yellowness values than their wheat-containing counterpart. Increase in the amount of buckwheat flour resulted in a decrease in cookie yellowness. Moreover, rise in

buckwheat flour content from 10 to 20% resulted in an increase in sensory scores for flavour, rupture and chewiness. Scanning electron micrographs revealed cohesive structure of gluten-free cookies indicating adequate raw material selection, component ratio, as well as processing conditions.

Gujral *et al.* (2019) utilized the broken rice, a byproduct of the rice milling industry at different levels to evaluate unleavened flat bread (chapatti) making properties of whole wheat flour. Chapattis were prepared by replacing whole wheat flour with broken rice flour up to 50% level. Mixolab studies revealed that incorporation of rice flour lowered dough development time and dough stability of whole wheat flour up to 23.49% and 78.33%, respectively. Lower retrogradation was observed in whole wheat rice flour blends as revealed from soluble starch/amylose. A positive correlation of mixolab retrogradation was observed with soluble starch and soluble amylose. Whole wheat flour chapatti (fresh and retrograded) containing different level of rice flour were also evaluated for glycemic index (GI), rapidly digestible starch (RDS) and slowly digestible starch (SDS). Chapattis containing rice flour demonstrated higher GI and RDS but lower SDS. RDS correlated positively with GI. Chapattis from the whole wheat rice flour blends had good consumer acceptability. Also, the formulated dough indicated decrease in DDT, dough stability and increase in destabilization of the gluten dough matrix and peak viscosity. Chapatti WA lowered on substituting whole wheat flour with broken rice flour up to a level of 50%. With increase in the substitution level of whole wheat flour with rice flour, the digestibility of starch increased. As a result the GI also increased. The results of the present study suggest the potential for encouraging the utilization of broken rice flour by substitution into wheat flour to prepare an economically viable composite flour for chapatti making.

Ameh *et al.* (2013) determined the effect of rice bran supplementation on some physico-chemical and sensory properties of wheat bread. Blends of wheat flour and rice bran (95:5, 90:10 and 85:15) were used to bake bread with 100%

wheat flour as control. Thereafter, proximate, vitamin and mineral composition, as well as the physical and sensory properties of the dough and bread loaves were determined, using standard methods of analysis. The moisture content, crude protein, crude fat, crude fibre and ash of the composite bread loaves increased significantly ( $p < 0.05$ ) from 21.07% to 23.67%, 12.04% to 13.10%, 1.57% to 3.77%, 1.76% to 2.91% and 1.46% to 2.41% respectively; while carbohydrate content decreased with increased level of supplementation from 62.10% to 54.14%. There were significant increases ( $p < 0.05$ ) in vitamin B1 (Thiamin) from 0.15 mg/100g to 0.47 mg/100g and B2 (Niacin) from 3.31 mg/100g to 4.04 mg/100g but no significant increase ( $p > 0.05$ ) in vitamin B3 (Riboflavin). Mineral content of the bread increased significantly ( $p < 0.05$ ) with increased level of supplementation from 9.32 mg/100g to 20.52 mg/100g (Iron), 80.74 mg/100g to 188.20 mg/100g (Potassium), 81.31 mg/100g to 130.70 mg/100g (Calcium) and 13.65 mg/100g to 132.22 mg/100g (Magnesium). However, there was a significant decrease ( $p < 0.05$ ) in sodium with increased level of supplementation from 305.25 mg/100g to 253.03 mg/100g. Though 100% wheat bread had better acceptability scores (7.95) compared to composite bread (7.20 for 95:5 blend), all the composite bread samples had significantly ( $p < 0.05$ ) higher values for nutritional parameters. There was therefore, a significant improvement in the nutritional composition of the wheat bread with rice bran supplementation.

### **2.2.2 Texture profile analysis and bread parameters of optimized flat bread.**

Itthivadhanapong and Sangnark (2016) evaluated the effect of substitution of black glutinous rice flour for normal wheat flour on batter and cake properties. Black glutinous rice flour was used to substitute 30, 50, 70 and 100% of wheat flour in a control cake formulation. Experimental data showed that Substitution of black waxy rice flour influenced the batter viscosity, resulting less viscous batters as the proportion of black rice flour increased. Moreover, the results also showed that the substitution of glutinous rice flour caused an increase in specific gravity and trended to decrease the specific volume of cake. The color of crust and crumb

cake progressively became darker as the level of black glutinous rice substitution increased. According to texture profile analysis, the cake with black glutinous rice flours had greater firmness, gumminess and chewiness values compared to the control cake with no added black glutinous rice flour. Hedonic sensory tests revealed that the cake prepared with black waxy rice flour had similar ( $P>0.05$ ) flavor, taste, texture and overall acceptable scores to that of the control sample. Subsequently, the functional properties of black waxy rice may lead it to be a nutritionally and economically important to the bakery industry.

Gujral *et al.* (2007) studied the effect of replacing wheat flour with wheat bran (0–10%), coarse wheat flour (0–20%) or with rice flour (0–20%) on the quality of cookies was studied. The cookie dough was subjected to Instrumental Texture Profile Analysis in order to determine dough cohesiveness and adhesiveness. After baking spread factor, puncture force and fracture strength of the cookies was also determined. The control dough had cohesiveness and adhesiveness values of 0.279 and 13.6Ns whereas control cookies had puncture force and fracture strength of 90.84N and 100.16N. Wheat bran increased dough cohesiveness and adhesiveness whereas coarse wheat flour had the opposite effect. Increasing levels of rice flour decreased cohesiveness but increased adhesiveness. Wheat bran and rice flour lowered the spread factor where as coarse wheat flour increased spread factor. Coarse wheat flour and rice flour lowered the fracture strength where as wheat bran increased fracture strength. Sensory evaluation revealed that increasing levels of wheat bran lowered the overall acceptability whereas rice flour and coarse wheat flour improved sensory scores.

Gupta *et al.* (2009) prepared Sponge cakes by incorporating barley flour (10, 20, 30 and 40% w/w) into wheat flours. The sponge cakes were evaluated for their physical, chemical, nutritional, textural and sensory attributes. All the prepared products exhibited high in fiber, mineral and protein contents when compared with the 100% wheat flour based product. Incorporation of barley flour improved the visual of the cake from pale cream to golden brown and texture

found to be softer as indicated by the instrumental texture profile analysis of the resulted cake. The cohesiveness and adhesiveness increased as barley flour incorporation from 0 to 40% and these texture properties was not increased further during storage up to 120 h. Incorporation of 20% barley flour into wheat flour for preparing cake was found to be optimum, containing rich in b-glucan, iron, calcium, zinc and highest sensory scores. While the texture characteristics showed 0.262 cohesiveness and 1.39 N mm adhesiveness. The prepared cake sample indicated that the product was nutritionally rich, softer and firmer as compared to the 100% wheat flour. The results indicated that the barley flour had an anti-staling effect during storage up to 120 hr. The addition of vegetable oil to the batter resulted in an improved texture.

Adeyeye *et al.* (2019) evaluated the quality characteristics and consumer acceptance of wheat-rice composite flour bread were. Substitution of rice flour was done in wheat flour from 0 to 100% and the composite flour was used to produce bread. The bread samples were subjected to proximate, physical and sensory analyses. The results showed significant differences ( $p \leq 0.05$ ) between the proximate compositions of bread samples studied. Bread from control (100% wheat flour) had moisture content of  $28.61 \pm 0.28\%$ . Bread from 10-50% wheat-rice composite flour had moisture contents ranged from  $28.04 \pm 0.41$  -  $24.81 \pm 0.40\%$ . The oven spring of the samples from control (100% wheat flour) had the highest value of  $1.12 \pm 0.28$  cm. The oven spring of wheat-rice composite bread ranged between  $1.00 \pm 0.22$  and  $0.82 \pm 0.38$  cm. There was inverse relationship between loaf weight (g), loaf volume and specific volume and the quantities of rice flour added to the wheat flour. The results of consumer acceptance showed that bread with 70:30 wheat: rice flour ratio was acceptable to the consumers. In conclusion, bread of good quality and good consumer acceptance could be made from wheat-rice composite flour.

Nasir *et al.* (2020) studied the chemical composition, colour analysis, of flour and bread. The rheological properties of dough and proximate, colour,

textural and organoleptic properties of amaranth wheat bread were also studied, Wheat flour was replaced by amaranth flour (AF) at 0-15% levels (100 : 0, 95 : 5, 90 : 10 and 85 : 15, respectively). AF supplementation increased the moisture (31.06 to 33.24%), ash (0.92 to 1.51%), protein (12.17 to 13.11%), fat (2.16 to 2.77%) and crude fibre content (1.11 to 1.72%) of the bread while the nitrogen-free extract and alkali water retention capacity decreased from 52.58 to 47.65% and 136.00 to 112.02%, respectively. A significant impact on the physical properties like the weight of bread (increased from 474.00 to 489.30 g), height (went down from 80.00 to 74.33 cm), loaf volume (decreased from 1580.00 to 1518.30 cm<sup>3</sup>) and specific volume (reduced from 3.32 to 3.10 cm<sup>3</sup> g<sup>-1</sup>) was observed with the replacement of wheat flour. Textural measurement depicted that hardness, chewiness, gumminess, springiness and cohesiveness increased with the substitution of amaranth flour. Rheological parameters like complex viscosity, loss modulus and storage modulus were also observed in all dough samples. Bread samples with 5%, 10% and 15% of AF showed lower yellowness (b \*) and higher lightness (L \*) and redness (a \*) values for crust colour while lower L \* and higher a \* and b \* values for crumb colour. The bread prepared by replacing 5% and 10% of AF is nutritionally as well as sensorially acceptable.

### **2.3 Effect of hydrocolloids on quality and shelf life stability of optimized flat bread**

Patil and Arya (2016) studied the effect of addition of various emulsifiers such as sodium stearoyl-2-lactylate (SSL), di acetyl tartaric acid ester of monoglyceride (DATEM) and glycerol mono-stearate (GMS). Further hydrocolloids (guar gum, carrageenan) and modified polysaccharides [hydroxypropyl methylcellulose (HPMC) and carboxymethyl cellulose] were added at the concentration ranging from 0.25 to 1 % on the basis of whole wheat flour to prepared the doughs. These thepladoughs were analyzed for rheology and theplas were analyzed for tear force. Additives helped in improvement of dough and thepla quality. Guar gum increased dough stickiness and strength to the

highest (31.12 and 1.76 g respectively). Also, guar gum decreased tear force value of thepla to 208.4 g. Tear force was found to be increasing with the duration of storage. Highest improvement in thepla dough and quality was obtained by the addition of guar gum at 0.75 % which retained the softest texture of thepla.

Shalini and Laxmi (2007) studied the effect of various hydrocolloids (guar gum, carboxymethylcellulose (CMC), hydroxypropylmethylcellulose (HPMC), k-carrageenan) on fresh chapatti quality as well as on stored chapatti texture. Improvement in chapatti quality parameters such as extensibility, force to tear, color characteristics and sensory acceptability were monitored. Quality parameters (extensibility, force to tear, color) and sensory properties of chapatti both when fresh and after storage for 2 and 5 days at room temperature ( $30 \pm 2$  °C) and refrigerated temperature ( $4 \pm 1$  °C) were analyzed. Hydrocolloids were incorporated at various levels ranging between 0.25% and 1.0% w/w of whole wheat flour. Amongst the hydrocolloids studied guar gum gave the highest extensibility for fresh and stored chapatti. The force required to tear the fresh chapatti was decreased with hydrocolloid addition however guar gum addition at 0.75% w/w of whole wheat flour gave the softest chapatti. There was no significant effect on color of chapattis due to addition of hydrocolloids and sensory acceptability was found to be higher than that of control chapatti.

### **2.3.1 Proximate composition**

Maghaydah *et al.* (2013) prepared three kinds of gluten-free bread in which wheat flour was substituted with rice and corn flour at a ratio of 5:1, respectively. Gluten was substituted using different hydrocolloids: 1% xanthan and 1% carrageenan (Mix A), GFB A; 1% xanthan and 1% pectin (Mix B), GFB B; and 1% carrageenan and 1% pectin (Mix C), GFB C. These three types of bread were compared to control bread produced from wheat flour (WB). Sponge and dough method with some modifications was used to produce the bread samples with a developed formula (0.8% yeast, 4.0% sugar, 2% salt, 7.0% shortening, 2.0% non-fat dry milk and 1% sodium stearoyl lactylate (SSL)). Determination of the

chemical composition, rheological properties and physical characteristics, as well as sensory evaluation of the bread samples, was undertaken. Results showed that the moisture content of WB bread (control) was significantly lower than that of all types of gluten-free bread and there was no significant difference in ash, protein and lipid contents among the gluten-free bread samples. GFB A, GFB B and GFB C displayed no significant differences in their specific volumes. The sensory evaluation showed that GFB C received the lowest sensory evaluation score. Therefore, GFB A and GFB B were the best gluten-free samples.

Wongklom *et al.* (2016) investigated the effect of xanthan gum and carboxymethylcellulose (CMC) on bread quality made from Hom Nil rice flour (HNRF). The results showed that moisture content, protein, ash, fat, carbohydrate and crude fiber content of the HNRF were 8.40%, 7.71%, 1.71%, 4.11%, 78.06% and 1.42%, respectively. The pasting temperature, trough, breakdown, final viscosity, peak viscosity, peak time and set back of HNRF were 86.28°C, 1074 cP, 254 cP, 2207 cP, 1327 cP, 5.8 mins and 1133.5 cP, respectively. HNRF was used to produce bread with varied xanthan gum and CMC in ratios of 3:0, 2:1, 1.5:1.5, 1:2 and 0:3 respectively. The results showed that the ratio of xanthan gum and CMC at 1:2 provided the higher acceptable liking score than others ( $p \leq 0.05$ ). The appearance, odor, softness and overall acceptance of bread were 6.37, 6.03, 6.03 and 6.10 respectively. Moisture content, protein, ash, fat, carbohydrate and crude fiber content were 30.16%, 6.74%, 2.12%, 6.88%, 54.10% and 1.36%, respectively. Hardness, springiness and chewiness of the Hom Nil bread were 7.02 g, 0.73 mm and 1.81 gmm respectively. The study revealed that it is possible to use Hom Nil rice flour made gluten free bread. Xanthan gum and CMC could be used to improve the bread quality. This product will be provided an alternate choice for consumer with celiac disease. Shelf life, consumer acceptance and purchase intent should be studied in the future to confirm their market potential for HNRF Bread.

Mir *et al.* (2014) prepared gluten-free cakes from two different varieties of water chestnut (Kashmir (WCF K) and Punjab (WCF P) flours. Hydrocolloids (sodium alginate, guar gum and carboxy methyl cellulose) were added to obtain desired body and texture. Proximate analysis and characterization of cakes was carried out. Cakes prepared from WCF (K) with carboxymethyl cellulose (CMC) (1%) had lower moisture, whereas WCF (K) with sodium alginate (1%) had higher ash content. Protein content was found higher in control sample followed by cake prepared from WCF (K) with sodium alginate (1%). Calorific value was higher in WCF (P) sodium alginate (1%) added cake and lower in case of WCF (K) prepared cake containing CMC (1%). Firmness was higher in cake prepared from WCF (K) with guar gum (1%) and cakes prepared from WCF (P) with guar gum (1%) were more acceptable in terms of physical appearance, crust, crumb color, flavor and mouthfeel. Sensory analysis of water chestnut cakes revealed that the cakes prepared from WCF (P) with guar gum (1%) were more acceptable to the sensory panel in terms of physical appearance, crust and crumb color, flavor and mouthfeel. Further studies on the utilization of this underutilized crop for preparation of various bakery products will help overcome celiac diseases and uplift the socioeconomic conditions of people associated with this trade in Jammu and Kashmir and Punjab.

### **2.3.2 Texture and bread parameters**

Patil and Arya (2018) investigated the effects of addition of hydrocolloids (guar gum, xanthan gum) and emulsifiers (sodium stearoyl 2 lactylate, glycerol monostearate) on the quality of formulated gluten free dough and flatbread. Simplex centroid design was employed for the purpose. Dough textural parameters (dough stickiness, dough strength, gumminess, elasticity) and flatbread characteristics (tear force, elasticity, hardness, chewiness and resilience) were studied. Texture profile analysis was done for both dough and flatbread samples. These additives lead to enhanced properties of gluten free dough and flatbread. The optimum formulation for these hydrocolloids and emulsifiers

contained guar gum (0.8%), xanthan gum (0.3%), glycerol monostearate (0.9%). This optimum formulation of additives produced gluten free dough and flatbread with better rheological and textural quality.

Harsono *et al.* (2021) investigated the effect of CMC concentration on the physicochemical and sensory properties of bread enriched with rice bran. The research design was a Randomized Block Design consisting of one factor which was the CMC concentration with five levels, 0%, 0.5%, 1%, 1.5% and 2% with five replications. The results showed that increasing CMC concentration decreased moisture content in bread enriched with rice bran, increased specific volume, decreased hardness, increased springiness, increased cohesiveness, increased preference sensory properties ease to bite, softness and moistness. The best treatment was 2% CMC addition. Bread enriched with rice bran with 2% CMC concentration has moisture content 41.79%, specific volume 3.61 cm<sup>3</sup>/g, hardness 326.93 g, springiness 0.95 mm, cohesiveness 0.67, preference for ease of bite 5.52 (slightly preferred), preference for softness 5.24 (slightly preferred) and preference for moistness 5.02 (slightly preferred)

Zelada *et al.* (2018) assessed the combined effect of guar gum (GG) and water content (WC) on the rheological properties of batter and the physicochemical and textural properties of bread. Batches of gluten-free bread used a base formulation of rice (50%), maize (30%) and quinoa flour (20%), with different levels of GG (2.5, 3.0 or 3.5%) and water (90, 100 or 110%) in a full factorial design. Higher GG doses ( $p < 0.001$ ) tended to produce batters of lower stickiness, work of adhesion and cohesive strength; yet, of higher firmness, consistency, cohesiveness and viscosity index. These batters yielded loaves of lower ( $p < 0.001$ ) specific volume and baking loss; and crumbs of lower ( $p < 0.001$ ) aw, pH, mean cell area, void fraction, mean cell aspect ratio; and higher ( $p < 0.001$ ) hardness, adhesiveness, springiness, cohesiveness, chewiness, resilience, mean cell density, cell size uniformity and mean cell compactness. The sticker and less consistent batters produced with higher WC rendered larger bread loaves

of softer and more cohesive and springy/resilient crumbs with greater mean cell size and void fraction. Gluten-free loaves of good appearance in terms of higher specific volume, lower crumb hardness, higher crumb springiness and open grain visual texture were obtained in formulations with 110% WC and GG doses between 2.5 and 3.0%.

Pahwa *et al.* (2017) studied the effect of the addition of different hydrocolloids and potato flour on the flat bread quality characteristics. Gluten-free whole grain flat bread was prepared by using whole maize: soybean: sorghum (2:1:1) flour after conducting preliminary trials on each formulation. Further, xanthan gum (0, 0.25, 0.50, 0.75 and 1 per cent), guar gum (0, 0.25, 0.50, 0.75 and 1 per cent) and potato flour (0, 5 and 10 per cent) were incorporated on flour weight basis for the preparation of flat bread. Specific volume, loaf height and loaf weight of flat bread were determined. Crumb firmness was decreased by guar gum and potato flour. On the basis of baking quality and sensory properties, most acceptable level of additives to be incorporated in gluten-free flat bread were xanthan gum -0.75 per cent, guar gum -0.50 per cent and potato flour -5 per cent.

Maleki and Milani.(2013) studied the effects of four hydrocolloids (guar, xanthan gum, carboxymethylcellulose (CMC) and hydroxypropylmethylcellulose (HPMC)) in three concentrations (0.1, 0.5 and 1 % w/w flour basis), on Barbari (Iranian bread) was investigated. Farinograph parameters, physical properties (specific volume, oven spring, height to width ratio, crumb to crust ratio) and the moisture content of fresh bread were analyzed. CMC and HPMC had the most noticeable effect on dough rheological properties; leading to a more strengthened dough. The hydrocolloids also improved the bread's physical properties. In addition, the best effect on moisture content was observed by 0.5% CMC, followed by 0.5% and 1% HPMC. Hydrocolloids did not unfavourably influence the sensory properties of bread. All sensory parameters were improved using hydrocolloids. Consequently, despite the improving effect of all hydrocolloids, cellulose derivatives could have better uses in bread-making processes.

Aboulnaga *et al.* (2018) examined three different natural hydrocolloids (xanthan, guar and Arabic gums) at three different levels 0.5, 1.0 and 1.5% to study their effect on bread quality. The obtained results revealed that, the farinograph parameters such as water absorption, stability of dough, extension resistance, energy and proportion number were increased by increasing the used gums amount from 0.5 to 1.5%. Meanwhile, degree of softening was decreased. The pan bread physical properties like loaf weight, loaf volume and specific volume were gradually increased with increase gums addition levels as compared to control sample. The results also confirmed the ability of hydrocolloids for improving bread freshness during storage periods. For sensory evaluation, data demonstrated that, there was significant effect on crumb color, texture, general appearance and overall acceptability pan bread due to addition of high level of hydrocolloids. While crust color and taste were significantly not differed. It could be concluded that, to obtained pan bread with a good quality than control, it should be added xanthan gum with a ratio of 1.0 -1.5% or guar gum with a level of 1.5% of the flour weight.

Olatidoeye *et al.* (2020) produced six breads samples from high quality cassava flour (HQCF) fromwheat/HQCF/hydrocolloid :T0100% wheatflour (control); T190:9: CMC; T290: 9: GG; T3,80: 18: CMC; T4,80: 18: GG; T570: 27: CMC;T670:27:GG. The flour blends were analyzed for colour and pasting properties while breads characteristics and sensory evaluation were performed in order to assess effect of hydrocolloids on bread. Significant differences at  $p < 0.05$  were found on the pasting properties of addition of hydrocolloids with lower pasting temperature (71oC) and time (6.08 min). Bread quality attributes such as loaf volume, specific loaf volume, oven spring, crust colour, crumb colour and firmness of the fresh breads significantly improved with the addition of hydrocolloids compared with bread produced without improvers. The results show that high quality cassava flour could be incorporated up to 18% with carboxymethylcellulose at 2% level without affecting its overall acceptability and

thereby enhance the potential for using locally produced flours in bread baking. Sensory score of bread from the addition of hydrocolloids were all acceptable by the panelist. The addition of hydrocolloids could be used as an effective means of improving the quality of gluten free bread.

### **2.3.3 Degree of staling**

Shaikh *et al.* (2007) examined the staling of chapattis both at room temperature and refrigerated temperature storage. Moisture content, water-soluble starch, in vitro enzyme digestibility, enthalpy change (DH), texture and sensory quality of chapattis, which are significantly affected during staling both at room and refrigerated temperature storage, were monitored over a storage period of one month. Moisture content, water-soluble starch and in vitro enzyme digestibility were found to decrease steadily during staling of chapattis at both room temperature and refrigerated temperature of storage. Enthalpy change, DH, as measured by DSC increased with storage time. The texture of chapattis became progressively harder with storage at both room and refrigerated temperature. A decrease in sensory quality and acceptability of the chapattis was observed with storage. The rate of staling was lower at refrigerated temperature. Most of the staling parameters studied showed good correlation. Texture showed the best overall correlation with all other staling parameters. In general, the correlation obtained at room temperature was better than that at refrigerated temperature.

Ozkoc *et al.* (2009) investigated the staling of breads baked in different ovens (microwave, infrared-microwave combination and conventional) with the help of mechanical (compression measurements), physicochemical (DSC, X-ray, FTIR) and rheological (RVA) methods. The effect of xanthan-guar gum blend addition on bread staling was also studied. Xanthan-guar gum blend at 0.5% concentration was used in bread formulation. The gums were mixed at equal concentrations to obtain the blend. After baking, the staling parameters of breads were monitored over 5 days storage. During storage, it was seen that hardness, retrogradation enthalpies, setback viscosity, crystallinity values and FTIR outputs

related to starch retrogradation of bread samples increased, whereas FTIR outputs related to moisture content of samples decreased significantly with time. The hardness, retrogradation enthalpy, setback viscosity and crystallinity values of microwave-baked samples were found to be highest among other heating modes. FTIR outputs related to starch retrogradation. Addition of xanthan-guar gum blend decreased hardness, retrogradation enthalpy and total mass crystallinity values of bread samples showing that staling was delayed.

Noorlaila *et al* (.2017) studied the effects of xanthan gum (XG) and hydroxypropyl methylcellulose (HPMC) in sponge cakes were. Hydrocolloids enhanced the thickening effect in batter that affected the textural attributes of sponge cakes. During storage, the structural changes in XG-cake resulted in higher hardness compared to HPMC-cake. Similar to XG, HPMC also contributed moistness to cake. The moisture loss of cake containing XG was slower than HPMC-cake. FTIR study showed absorption of OH at region of 3600–2900  $\text{cm}^{-1}$  that explained the strong interaction of water in cake containing XG compared to other cake formulations. The strengthening effects of XG increase the rigidity of batter and crumb hardness of sponge cakes. For stored cake, the mechanism of staling (starch retrogradation and moisture distribution) was continuously occurred in all sponge cakes formulations. The decreasing of moisture content and water activity, increasing of moisture loss and hardness and the changes in OH distribution in FTIR over the storage from day 0 to day 6 confirmed the staling process occurred in sponge cakes. The addition of XG and HPMC were able to reduce the staling process by minimizing the water loss that retained more moistness. However, XG and HPMC could not interrupt the starch retrogradation within the cake. Moreover, its interaction with starch resulted in higher values of crumb hardness. The continuity of starch and protein network was undisrupted in XG cake, thus resulted in higher values of crumb hardness compared to HPMC cake. For sponge cake, HPMC is more suitable to be added as additives than XG because it imparts the softening effects in crumb texture.

## 2.4 Storage studies of low gluten optimized flat bread

Ho *et al.* (2014) investigated the effect of white bread (BCtr), bread incorporated with banana pseudo-stem flour at 100 g/kg level (B10BPF) and B10BPF added with hydrocolloids at 8 g/kg (based on flour basis), i.e. xanthan gum (B10BPFXG) or sodium carboxy-methyl cellulose (B10BPFCMC) and were determined for moisture, water activity, texture, thermal and microbiological quality during storage (3 days). Results indicated that all the formulated bread crust showed an increase in moisture and water activity during storage, but was vice versa for the respective bread crumb. All the formulated breads showed an ultimate trend in hardness with time. The composite bread crumbs with the exception of B10BPFCMC were observed to be harder than the BCtr. Composite breads showed higher onset and peak temperatures values than BCtr. BCtr had higher gelatinization enthalpy change temperature than composite breads with the exception of B10BPFCMC. Population of aerobic plate counts, mould and yeast count was observed increasing with the time of storage.

Wanjuu *et al.* (2018) studied to determine the physiochemical properties and shelf-life of orange-fleshed sweet potato OFSP puree-wheat flour composite bread (30% puree), compared to standard, 100% wheat flour, bread. Freshly baked bread samples were stored at 7, 20, 25 and 30°C and monitored for moisture content, water activity, color, texture, volume, carotenoids and microbial load. The moisture content,  $\beta$ -carotene content and color of bread significantly decreased with increase in storage temperature and time ( $p < 0.05$ ). Bread made with OFSP puree had a longer shelf-life, showing spoilage on day six compared with the white bread, which spoiled on the fourth day. This is attributed to the significantly higher water activity in white bread than in the OFSP bread. The substitution of wheat with OFSP puree resulted in reduced extensibility of gluten, thus, specific volume of white bread was significantly ( $p < 0.05$ ) higher than that in OFSP puree bread. Refrigeration increased crumb firmness, chewiness and cohesiveness in

both types of bread. In conclusion, OFSP puree increases the water binding capacity of the bread, which reduces water activity and increases its shelf-life.

Maleki *et al.* (2012) investigated the effects of 0.1, 0.5 and 1.0 % of the bread-improving hydrocolloids (guar gum, xanthan gum, carboxymethylcellulose and hydroxypropylmethylcellulose) on staling rate of Barbari bread. Bread staling was studied during the 1st, 3rd and 5th day of storage. Samples containing hydroxypropylmethylcellulose (HPMC) and carboxymethylcellulose (CMC) showed lower loss of moisture content. Using 0.5% HPMC in fresh bread led to the softest crumb. Two days after baking, CMC is more effective than the other three hydrocolloids, but with increase in storage time, HPMC showed better results. Adding hydrocolloids caused more retention of water-soluble starch (WSS) in fresh and stored bread. Differential Scanning Calorimetry (DSC) analysis showed that adding hydrocolloids led to an improvement in thermal properties. The antistaling effect of hydrocolloids might be due to their interaction with other bread constituents. Amongst all hydrocolloids, cellulose derivatives are more influential.

Amaral *et al.* (2016) investigated some of the factors that might influence RS formation in wheat bread, namely (1) formulation; (2) loaf size; (3) baking conditions; and (4) storage conditions. Seven bread formulations were prepared: reference recipe (control) and six experimental formulations. The effect of the loaf size and the baking conditions was also tested. Finally, the effect of storage was tested by keeping control breads under different storage conditions (temperature/time). Moisture and resistant starch contents were evaluated in all breads. A higher level of moisture in the dough and a larger loaf size enhanced the RS content. An extended baking process also favored significantly the formation of RS. Storing the bread at room temperature for 3 days was shown to further increase the RS content. It is possible to increase the RS content of bread by modifying the ingredients ratio and processing conditions. The bread storage conditions also influenced the content of RS: Keeping the bread at room

temperature for 3 days seems to be the way to further increase the RS content (over 26 %).

Majzoobi *et al.* (2011) Production of part-baked bread is a successful method to postpone bread staling that has been applied widely for production of loaves. In this research, production and some physical characteristics of part-baked flat bread (Barbari) including hardness, volume, color, weight loss and microstructure were studied during the storage of the samples at ambient (25°C) and freezing (-18°C) temperatures. The part-baked bread had higher moisture content than the control and full-baked breads. However, it had a shelf-life of 72 hours, which was shorter than the control at ambient temperature. Full-baking could level out the effects of staling and, hence, the quality of the full-baked bread was similar to that of the fresh bread. For the frozen samples, the optimum storage time was two months. The undesirable effects of frozen storage were more significant for the part baked bread. Moreover, full-baking could compensate some of the adverse effects of freezing and the resultant bread had superior quality compared with the control.

Giri *et al.* (2021) investigated the supplementation of additives (hydrocolloids) on quality, physicochemical, microbiological and sensory characteristics of wheat flat breads. In order to delay staling by using additives in chapati making, additives (Vital Gluten, Oxidised Corn Starch and K-carrageenan) were incorporated at different concentrations (0.15, 0.50 and 0.10%) with wheat flour. Physical Characteristics (moisture loss and baking time), chemical (Protein content, Fat content, Starch content and Ash content), microbiological (Yeasts and Moulds count) and sensory properties of developed wheat chapatis were investigated by applying different experiments and results were compared with those of control chapati prepared with whole wheat flour. With respect to the control wheat chapati, almost in terms of all attributes wheat chapati developed by incorporating K-carrageenan as an additive, showed the

highest anti-staling rate and was also greatly acceptable when compared with all the other chapatti samples.

## Chapter 3

### MATERIALS AND METHODS

The present investigation entitled “**Development of rice flour incorporated wheat based low gluten shelf stable Kashmiri flat bread**” was carried out in the Division of Food Science & Technology (FST), Sher-e-Kashmir University of Agricultural Science and Technology of Kashmir (SKUAST-K), Shalimar. This section enlists the raw material used and elaborates the processing techniques, analytical procedures, organoleptic evaluation and statistical methods followed during research.

#### 3.1 Procurement of raw materials

Refined wheat (*Triticumaestivum* L.) flour was purchased from local market of Srinagar, Kashmir. The paddy (Variety *Jhelum*) was obtained from Mountain Research Center for Field Crops (MRCFC), Khudwani, Anantnag, J&K, India of SKUAST-K. Paddy was subjected to milling in modern rice mill (ASR RM 209) at the Division of Food Science and Technology, SKUAST-Kashmir, Shalimar, J&K. The small broken rice grains were ground to fineness that passed through 200 µm sieve. Sieved rice flour samples were packed in low density polyethylene (LDPE) pouches for further use.

##### 3.1.2 Other raw materials used

###### 3.1.2.1 Salt

Iodised table salt (TATA) was procured from the local market for its use in the preparation of bakery products.

###### 3.1.2.2 Baker’s yeast

Fresh compressed yeast (*Saccharomyces cerevisiae*) manufactured by S.A.F yeast Co. Ltd, Bombay was obtained from local market.

### **3.1.2.3 Sodium stearyl -2-lactylate, Guar gum and Carboxyl methylcellulose**

AR grade Sodium stearyl-2-lactylate, Guar gum and carboxymethyl cellulose (High Purity Laboratory Chemicals Private Limited, Mumbai) were procured from the market.

### **3.1.2.4 Sodium bicarbonate**

High purity sodium bicarbonate was procured from the Division of Food Science & Technology (SKUAST -K), Shalimar.

### **3.1.2.5 Packaging material**

Metalized polyester pouches procured from the local market was used as the packaging material to store flat breads.

## **3.2 Physicochemical characteristics of wheat and rice flour**

The raw materials (i.e. wheat and rice flour) were evaluated for below mentioned physicochemical attributes.

### **3.2.1 Proximate composition**

#### **3.2.1.1 Moisture content (%)**

Pre-weighed samples (2 g) were dried in hot oven (Make: Tanco India ltd) at  $130\pm 1^{\circ}\text{C}$  for one hour and moisture content in per cent was calculated from loss in weight (AACC, 2010).

$$\text{Moisture content (\%)} = \frac{\text{Weight of original sample(g)} - \text{weight of dried sample(g)}}{\text{Weight of original sample(g)}} \times 100$$

#### **3.2.1.2 Ash content (%)**

Ash content of wheat flour and rice flour was determined according to the procedure of AACC (2010). Three gram of each replicate sample was placed individually in pre-weighed crucible, kept in muffle furnace at a temperature of  $600^{\circ}\text{C}$  for about six hours. The crucibles were then cooled in a desiccator and weighed accurately. Per cent ash content was determined by using the following equation:

$$\text{Ash (\%)} = \frac{\text{Weight of ash (g)}}{\text{Weight of sample (g)}} \times 100$$

### 3.2.1.3 Crude protein (%)

Protein content was determined in the Division of Food Science and Technology (SKUAST K), Shalimar by Micro-Kjeldahl method (AACC, 2010). The accepted method was as follows:

Micro-kjeldahl method was used to determine nitrogen content. Half gram of Samples in powdered form per replicate was placed in Kjeldahl tubes and 5g of digestion mixture (potassium sulphate + iron sulphate + copper sulphate in the ratio 5:0.5:0.25) was added. After adding 10 mL of concentrated H<sub>2</sub>SO<sub>4</sub>, the mixture was heated till colour changed to green. Then tubes were cooled and 10 mL of distilled water was added to each sample. Then tubes were fitted in assembly. Mixture from tubes was dipped in flask fitted in assembly containing 25 mL of boric acid (4.00%) and 5 mL of mixed indicator. Then 40-50 mL of NaOH (40.00%) was added to it till colour changed to brown. Flask containing boric acid and indicator was titrated with 0.1 N HCL till colour changed to brown. The resulting N<sub>2</sub> content was multiplied by a factor 5.95 to convert into crude protein content.

Protein estimation was calculated from nitrogen content (N %) in accordance with following formula:

$$\text{Nitrogen (\%)} = \frac{\text{Titre value} \times \text{Normality of HCl} \times 14}{\text{Weight of sample (g)}} \times 100$$

$$\text{Crude protein (\%)} = \text{N\%} \times 5.95$$

### 3.2.1.4 Crude fiber (%)

Crude fiber was estimated by following the standard procedures given by AACC (2010). Crude fiber was determined by fibre tech apparatus.

One gram samples was subjected to acid hydrolysis with 2.5 N HCL followed by alkali digestion with 0.1N NaOH. The residue so obtained was then

washed with double distilled water and ignited in a muffle furnace at 600°C for 6 hours. At high temperature, the inorganic matter in the residue got oxidized and inorganic residue or ash was left behind. The difference in the weight before and after process was then determined to calculate the per cent crude fibre in sample.

$$\text{Crude fibre (\%)} = \frac{W_1 - W_2}{W} \times 100$$

Where,

$W_1$ : weight of crucible with dry residue (g)

$W_2$ : weight of crucible with ash (g)

$W$ : weight of sample (g)

### 3.2.1.5 Crude fat (%)

Crude fat was determined by using petroleum ether as a solvent in the Soxhlet apparatus (SCS2, Pelican equipment, Chennai) according to AACC (2010) method. The results were expressed as per cent fat. 5 g of sample was placed in thimble which was placed in extraction unit. The extraction flask containing petroleum ether 2/3 of total volume was connected to extractor. The sample was extracted for 6 hours on a water bath. Petroleum ether was then evaporated by distillation and the extraction flask was then cooled and weighed. Crude fat was then calculated by using following equation:

$$\text{Crude fat (\%)} = \frac{B - A}{C} \times 100$$

Where,

A = Weight of clean dry flask (g)

B = Weight of flask with fat (g)

C = weight of Sample (g)

### 3.2.1.6 Carbohydrates (%)

The percentage carbohydrate content of each replicate sample was calculated by subtraction method as follows:

$$\text{Carbohydrate (\%)} = 100 - \% (\text{Protein} + \text{Moisture} + \text{Fat} + \text{Ash} + \text{Crude Fibre})$$

### 3.2.1.7 Total sugar (%)

Total sugars were determined by the methods described by Ranganna (1986) with slight modifications. To a known quantity of sample (10 g), 10 ml of 45% lead acetate solution was added and after 10 to 20 min, 5 g potassium oxalate was mixed. The content was filtered through Whatman No. 41 filter paper and the volume of the filtrate was made up to 100 ml with water. 75 ml of this filtrate was titrated against Fehling's solutions A and B (5 ml each). The remaining 25 ml filtrate was mixed with 5 ml conc. HCl and kept overnight. It was then, neutralized with 10% NaOH solution using phenolphthalein as an indicator. The volume of this pink coloured solution was made up to 75 ml and then, titrated against Fehling's solutions A and B (5 ml each).

$$\text{Per cent total sugar (as invert sugars)} = \frac{0.05 \times V_1 \times V_2}{T \times W \times 25} \times 100$$

Where,

$V_1$  = Volume of the extract made up to 100 ml.

$V_2$  = volume made up after neutralization.

T = Titre value.

W = weight or volume of sample taken.

### 3.2.1.8 Reducing sugars (%)

Reducing sugars were estimated by phenol sulphuric acid method (Dubois *et al.*, 1956). 100 mg of ground sample was hydrolysed by keeping in boiling water bath for 3 hrs with 5 ml of 2.5N HCl and cooled to room temperature. The solution was neutralised with solid  $\text{Na}_2\text{CO}_3$  until the effervescence ceases and the

volume was made upto 100 ml with distilled water. The contents were then centrifuged at 8000 rpm for 30 min at 27 °C. 1 ml of supernatant was diluted to 100 ml with distilled water. About 1 ml diluted sample was transferred in test tube and 1ml of 5 per cent phenol, 5 ml of concentrated sulphuric acid was added. The mixture was shaken well and kept in water bath maintained at 30 °C for 20 min. The absorbance of the solution was measured at 490 nm in spectrophotometer. Reducing sugar in test sample was calculated using standard graph prepared with standard solution of glucose (Appendix-I).

#### **3.2.1.9 Non-reducing sugars (%)**

Non reducing sugars were determined by the difference method as follows:

$$\text{Non-reducing sugars (\%)} = \text{Total sugars (\%)} - \text{reducing sugars (\%)}$$

#### **3.2.1.10 Resistant starch (%)**

Resistant starch content of sample was determined by following the procedures of Goni *et al.* (1997). Samples with low water content were milled to pass through a 1 mm sieve. 100 mg of the dry milled sample was weighed into a 50 mL centrifuge tube. 10 mL of KCl-HCl buffer (pH 1.5) was added followed by the addition of 0.2 mL of the pepsin solution (1 g pepsin/10 mL buffer KCl-HCl). The solution was mixed well and kept in a water bath at 40°C for 60 min with constant shaking. The samples were taken out of the water bath and cooled to room temperature. 9 mL of 0.1 M Trismaleate buffer (pH 6.9) was added which was followed by the addition of 1 mL of the  $\alpha$ -amylase solution (40 mg  $\alpha$ -amylase per mL Trismaleate buffer). The solution was mixed well and incubated with constant shaking at 37°C in a temperature controlled water bath (Thermotech, TIC-4000N) for 16 hours. The samples were centrifuged for 15 min at 3000 g and the supernatant was discarded. About 3 mL of distilled water was added to the residue, carefully moistening the sample and 3 mL of the 4 M KOH was added with mixing and the solution was left for 30 min at room temperature with constant shaking. Approximately, 5.5 mL of 2M HCl and 3 mL of 0.4 M sodium

acetate buffer (pH 4.75) was added followed by the addition of 80  $\mu$ L of amyloglucosidase, mixing and kept in a water bath at 60°C with constant shaking. It was then centrifuged at 3000 g for 15 min and the supernatant was collected and saved in a volumetric flask. The residue was washed at least once with 10 mL of distilled water, centrifuged again and the supernatant was combined with that obtained previously. The volume was made up to 500 mL. Glucose content (mg) of the sample was determined. The resistant starch (RS) content of the sample was calculated as mg of glucose  $\times$  0.9.

#### **3.2.1.11 Total Starch (%)**

The total starch was determined by an enzymatic colorimetric method, AOAC International method 996.11 (AOAC, 2007), with an assay kit from Megazyme International Ltd. (Wicklow, Ireland). Briefly, samples were ground through a 0.5-mm screen and 100.0 mg of sample was added to a test tube. Next, 0.2 mL of ethanol solution (80%, v/v) was added into the tube and mixed to wet the sample. Next, 3.0 mL of thermostable  $\alpha$ -amylase was immediately added and the tubes were boiled for 6 min and stirred at 2-min intervals. Tubes were then placed in a 50°C bath to rest for 5 min. Next, 0.1 mL of amyloglucosidase was added into each tube. Tubes were then stirred and incubated for 30 min and then filled to a volume of 10 mL with distilled water followed by centrifugation at 1,800  $\times$  g for 10 min at room temperature. Next, 1.0 mL of aliquots from the supernatant was diluted to 10 mL with distilled water. Then, 0.1 mL of this diluted solution was placed into a clean test tube. Glucose oxi-dase/peroxidase reagent (3 mL) was added to each tube and incubated at 50°C for 20 min. For blanks, 0.1 mL of water was used instead of 0.1 mL of diluted solution and the other added reagents were all the same. Samples were read for absorbance at 510 nm. Analysis was conducted in duplicate.

### 3.2.1.12 Amylose (%)

Amylose content of the samples was determined by colorimetric measurement of blue amylose-iodine complex (Juliano, 1971; Mir *et al.*, 2013). Hundred milligram of sample was weighed into a 100 mL volumetric flask and mixed with 1 mL of 95% ethanol, care was taken to prevent washing down of sample adhered to side of the flasks. Then, 9 mL of 1 N NaOH was added and heated in a boiling water bath for 10 min and cooled to room temperature. Samples were diluted by volume make up to 100 mL by adding distilled water. The solution was vortexed vigorously and 1 mg/mL solution was obtained and allowed to stand for 2 hours before continuing to next steps. Five mL of sample solutions and standard mixture of amylose prepared for working solutions was pipetted out into 100 mL volumetric flasks, containing about 50 mL distilled water. One mL of 0.1N acetic acid was added to each flask followed by mixing and allowed to stand for 20 min. After 10 min incubation at room temperature, the absorbance at 620 nm was analyzed with a spectrophotometer (ECIL, UV 5704SS) and the amylose content was calculated based on the standard curve as given in below equation:

$$\text{Amylose content (\%)} = \frac{\text{Amylose concentration from standard curve (mg/100 ml)} \times 100}{5 \times \text{weight of dry rice starch (g)}}$$

### 3.2.1.13 Amylopectin (%)

Amylopectin was calculated using the following equation explained by Torruco-Uco *et al.* (2006). The average amylose content value was taken for the calculation.

$$\text{Amylopectin} = (100 - \text{Amylose \%})$$

### 3.2.1.14 Damaged starch (%)

The damaged starch content in the flour was determined in accordance with the approved method 76-31 of the American Association of Cereal Chemists (AACC 2000). Starch damage level was calculated by using following formula:

$$\text{Starch Damage (\%)} = \Delta E \times F / W \times 8.1$$

Where,

$\Delta E$  = absorbance (reaction) read against the reagent blank.

$F$  = 150 ( $\mu$  of glucose)/absorbance of 150 $\mu$ g of glucose

$W$  = the weight in milligrams of flour analysed.

### **3.2.1.15 Wet gluten**

The following AACC method 38-12 (AACC, 2010) was used to determine the gluten content of each flour sample:

25grams of each replicate sample was transferred into metal vessel. Drop by drop 12 ml sodium chloride solution was put into metal vessel from burette while continuously stirring the flour. Then dough balls were made carefully to avoid loss of flour and their weight was recorded. The dough balls were placed inside the beaker (250 ml capacity), with wet paper for rest, for 30 minutes. With the palm of hand, sodium chloride solution was allowed to drip into it. The washing time depended on gluten content, but generally it was about 8 minutes. Washing solution adhered to gluten balls was eliminated by holding each ball between the fingers of one hand and compressing it briefly. The wet gluten content, was expressed as a percentage by mass of the original flour mass as under:

$$\text{Wet gluten content (\%)} = \frac{\text{Weight of gluten content (Weight of sample + 12)}}{\text{Weight of dough ball} \times \text{weight of sample}} \times 100$$

Where, 12 is the volume of sodium chloride solution in ml.

### **3.2.1.16 Falling number (sec)**

The slurry of 7 g of sample with 25 mL of water was used to determine the falling number values (sec) on the Falling Number AB apparatus according to AACC (2005) procedure.

### **3.2.1.17 Mineral profile (mg/100g)**

Mineral estimation was done after dry ashing of samples using atomic absorption spectrophotometer (Labtronics, Model LT2100) (Wani and Kumar, 2015). About 2.0 g of sample was digested with di-acid blend (HNO<sub>3</sub>:HClO<sub>4</sub>, 5:1, v/v). Double distilled water was used for dissolution of digested material, which was then filtered using Whatman no. 42. The filtrate obtained was made to 50 mL using double distilled water. This was then used for the determination of minerals.

### **3.2.2 Rheological properties**

#### **3.2.2.1 Pasting properties**

Pasting properties of sample flours were determined using Rapid Visco Analyser (RVA TECMASTER, Perten instruments, Australia). Each Flour samples (3.45 g) was taken in RVA aluminium canisters and 25 mL of distilled water was added to it. Then subjected to a programmed heating and cooling cycles which was held at 50°C for 1 minute and heated to 95°C for 2 minutes followed by cooling to 50°C for 2 minutes. There after sample were cooled to 50°C for 7 minutes and then held at 50°C for 2 minutes. The centrifuge rotating speed was maintained at 160 rpm. Observation for various parameters of pasting properties were recorded which included pasting temperature, peak viscosity, hold/trough viscosity (minimum viscosity at 95°C), final viscosity (viscosity at 50°C), breakdown viscosity (peak viscosity – hold viscosity), setback viscosity (final viscosity – hold viscosity) and peak time.

### **3.2.3 Farinographic characteristics**

The dough-mixing properties of the wheat and rice flours were examined with the Brabender farinograph (Brabender, Duisburg, Germany) according to the constant flour weight procedure (AACC, 2005). Sample (50 g) was taken in the mixing bowl. The mixing bowl and DIDI water were kept at 30°C for 60 min to maintain uniform temperature. Preliminary titration was carried out by running the

machine for 1 min until zero min line on the scale was reached. Water was added to the sample from a burette equal to its expected water absorption capacity and allowed to mix. Quantity of water was added such that maximum consistency of the dough was attained at the centre of farinogram band {500 Brabender Unit (BU)}. For final titration, whole of the water was added within 25 s and sample run for 25 min. The curve was interpreted for following parameters.

**Arrival time (min):** Arrival time is the point on the graph where the top of the curve reaches the 500 BU point and indicates the rate of absorption (minutes/BU).

**Degree of softening (BU):** it is defined as the difference (in BU) between the line of the consistency and the medium line of the torque curve, 12 min after weakening begins

**Water absorption capacity (%):** Amount of water (per cent) required to position the centre of the curve at the 500 BU line.

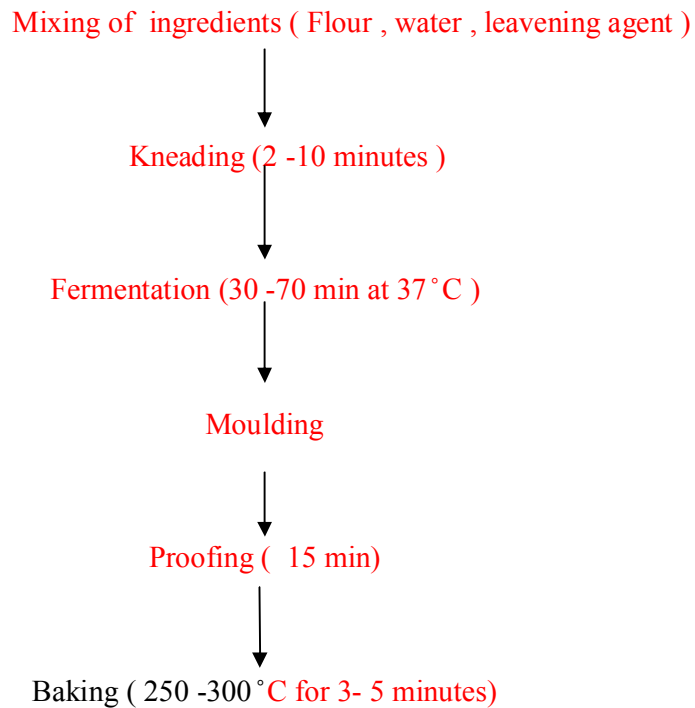
**Dough development time (min):** It is the time (min) to the nearest half min from the first addition of water to the development of maximum consistency of the dough.

**Dough stability (min):** It is defined as the difference in time to the nearest half min between the points where top of the curve first intercepts (arrival time).

**Mixing tolerance index (BU):** Difference in BU from top of curve at the peak to the top of curve measured after 5 minutes

### **3.3 Process optimization for the development of rice flour incorporated wheat flour based flat bread (Girda, kashmiri flat bread)**

The optimisation process for flat bread preparation shall be done by numerical optimisation. Flat bread shall be prepared as per the given flowchart



### 3.3.1 Method of preparation of low gluten flat bread

Flat breads were prepared from each composite flour combination by following the method reported by (Gujral & Gaur, 2002; Rao *et al.*, 1986) as shown in Table.1 (flour 100 g, dry yeast 2g, salt 2 g, sodium bicarbonate 1g). Each combination was mixed with optimum water in a planetary mixer for 2-10 minutes (Plate 1) according to the experimental design (Table 3.1), The optimum water was determined subjectively till smooth, cohesive, non- sticky dough which is easy to handle and suitable for continuous sheeting without cracking was obtained. The dough was then allowed to ferment in an incubator for 30-70 min at 37°C after that given a rest 5 minutes. Dough (60g) was rounded, placed in the centre of a specially designed platform. The dough was rolled with the help of a wooden rolling pin and given a round circular shape. The raw flat breads were carefully removed from the platform and were baked in a baking oven for 250-300°C for (3- 5 minutes) according to the experimental design (Table 3.1). Flat breads were allowed to cool for 10 min at 25 °C and used for further analysis (Plate 2)



**Plate 1: Planetary mixer used for flat bread preparation**



**Plate 2: Baking Oven used for flat bread preparation**

### 3.3.2 Experimental design

Central Composite Rotatable Design (CCRD) was used to incorporate four independent variables in the design used for flat bread making process. The independent variables considered were composition, i.e. Rice : wheat flour (A), mixing time (min) (B), fermentation time (min) (C) and baking temperature (°C) (D). The independent variables and variation levels for flat bread making process are given in Table 3.1.

Response surface methodology was applied for experimental data. The response surface experiments in terms of actual levels for low-gluten flat bread making process are presented in Table 3.2. The results were analyzed by a multiple linear regression method to describe the effects of variables in the models derived. Experimental data was fitted to the selected models and regression coefficients were obtained.

Responses obtained as a result of the proposed experimental design were subjected to regression analysis in order to assess the effects of composition, mixing time, fermentation time and baking temperature, on product characteristics. The individual, quadratic and interactive effects of each variable on product characteristics were determined. Second order polynomial regression models were established for the dependent variables to fit experimental data for each response using statistical software Design-Expert 12 (Stat-Ease Inc, Minneapolis, MN, USA).

$$y_i = b_0 + \sum_{i=1}^4 b_i x_i + \sum_{i=1}^4 b_{ii} x_i^2 + \sum_{i=1}^4 \sum_{j=1}^4 b_{ij} x_i x_j$$

where  $x_i$  ( $i = 1, 2, 3, 4$ ) are independent variables (Composition, mixing time, fermentation time and baking temperature respectively) and  $b_0$ ,  $b_i$ ,  $b_{ii}$  and  $b_{ij}$  are coefficient for intercept, linear, quadratic and interactive effects respectively. Data shall be analyzed by multiple regression analysis and statistical significance of the terms shall be examined by analysis of variance (ANOVA) for each response.

**Table 3.1: Process variables used in the central composite rotatable design (CCRD) for four independent variables in low gluten flat bread making process**

Process variables	Code	Variables Level Codes				
		-2	-1	0	+1	+2
Composition% (Rice Flour : wheat flour)	A	0:100	15:85	25:75	40:60	55:45
Mixing Time (min)	B	2	4	6	8	10
FermentationTime (min)	C	30	40	50	60	70
BakingTemperature (°C)	D	250	262	275	287	300

**Table 3.2: Response surface experiment in terms of actual levels for low-gluten flat bread making process**

Standard	Composition % Rice :wheat	Mixing time(min)	Fermentation time(min)	Baking temperature(°C)
1.	25:75	6	30	275
2.	15:85	8	60	262
3.	40:60	4	40	262
4.	15:85	4	40	287
5.	25:75	6	50	250
6.	15:85	8	60	287
7.	25:75	6	50	275
8.	55:45	6	50	275
9.	25:75	2	50	275
10.	0:100	6	50	275
11.	15:85	8	40	287
12.	15:85	4	60	262
13.	40:60	8	40	262
14.	25:75	6	50	275
15.	40:60	4	60	262
16.	15:85	4	40	262
17.	15:85	4	60	287
18.	25:75	6	70	275
19.	40:60	4	60	287
20.	15:85	8	40	262
21.	40:60	8	60	287
22.	25:75	10	50	275
23.	40:60	8	60	262
24.	25:75	6	50	275
25.	25:75	6	50	300
26.	25:75	6	50	275
27.	40:60	4	40	287
28.	25:75	6	50	275
29.	40:60	8	40	287
30.	25:75	6	50	275

### **3.3.3 Product responses of low-gluten flat breads.**

#### **3.3.3.1 Texture profile Analysis (TPA)**

Texture profile analysis of brown rice flour incorporated wheat based flat bread samples were performed at room temperature by using a TA-XT2 Texture Analyser (Ltd in Godalming, Surrey UK). The texture was measured by adjusting the portion of the compression plunger until it barely touched the surface of the bread at the centre of the sample. A sample of size was taken from the middle of the bread and placed under the cylinder probe (p/36 cylinder probe (36 mm) to make a flat surface at all time. The compression test was done by using a load cell of 5 kg, 1.6 mm/s test speed, cycle number 2, compression distance 25% and force 0.05 N.A TA-XT2 Texture Analyser was used with the Texture Exponent 32 software to measure the Hardness (N), Cohesiveness, Springiness (mm), Gumminess (N) and Chewiness (N) from TPA curves. The test was performed in accordance with the procedure given by Chung *et al.* (2014).

#### **3.3.3.2 Overall acceptability**

Flat breads were evaluated for sensory attributes (colour, flavour, texture, mouthfeel and overall acceptability) through a panel of ten semi-trained judges using 5-point hedonic scale. The proforma given in Appendix-I1 was used for sensory evaluation by ten semi-trained panellists from Division of Food Science and Technology.

#### **3.3.3.3 Instrumental color**

Colour was determined by using Hunter Lab colourimeter (Model SN3001476, Accuracy Micro-sensors, New York). The instrument was calibrated with the user supplied black plate calibration standards that were used for Zero setting. Minotta supplied white calibration setting were used for white calibration. The samples were uniformly packed in clean petriplates with lids. The instrument was placed on the plate and their exposure at different places was conducted. Reading were displayed as L\*, a\* and b\* colour parameter according to the

CIELAB system of colour measurement.  $L^*$  (Luminosity or brilliance) varies from black (zero) to white (100),  $a^*$  from red (+) to green (-) and  $b^*$  from yellow (+) to blue (-).

### **3.3.3.4 Flat bread (Girda ) parameters**

#### **3.3.3.4.1 Spread ratio (W/T)**

Spread ratio was calculated by dividing the average value of diameter by average value of thickness of flat breads. Spread ratio of samples was measured by following the procedure as described by Bose *et al.* (2010).

$$\text{Spread ratio} = \frac{\text{Width}}{\text{Thickness}}$$

#### **3.3.3.4.2 Volume index (cm)**

Volume index of samples was measured by following the procedure as described by Turabi *et al.* (2008). The flat breads were split into half and thickness of one half was measured using Vernier callipers at three different points. The average value of the thickness (mm) was calculated on the basis of ten observations.

#### **3.3.3.4.3 Width (mm)**

Width of flat breads were measured by laying three breads edge to edge separately with the help of a scale, then rotating them 90° and again measuring the width (mm) of three breads separately and average value was calculated on the basis of ten observations (Islam *et al.*, 2012).

#### **3.3.3.4.4 Thickness (mm)**

Thickness was measured by stacking three flat bread separately on top of each other and average thickness (mm) was calculated on the basis of ten observations (Islam *et al.*, 2012).

#### **3.3.3.4.5 Weight of flat bread (g)**

The weights of the breads were obtained by using Feili *et al.*, method. Bread samples were placed on the weighing balance that have previous zero and the weight values were recorded for each sample.

#### **3.3.3.4.6 Height (mm)**

To determine the height (H), flat breads were taken from the middle of the loaf and placed edge to edge. The height of three bread was measured by a scale in mm. The breads were rotated at an angle of 90° for duplicate reading. This was repeated thrice and the average height was taken in millimeters.

#### **3.3.3.4.7 Loaf volume and specific volume (cm<sup>3</sup>/g)**

Flat bread loaf volume was determined using the rapeseed displacement method (AOAC, 2000). Briefly, a container was filled with rapeseed and the volume of the rapeseed was measured using a measuring cylinder (V1). Then, the bread sample was placed into the container and the volume of the rapeseed with the bread sample was measured and noted as V2. The analysis was performed with triplicate samples. The volume of each loaf was calculated using the equation:

$$\text{Loaf volume} = V1 - V2 \text{ mL}$$

Specific volume (cm<sup>3</sup>/g) was determined by dividing the loaf volume by the loaf weight as described by See *et al.* (2007) and Feili *et al.* (2013).

#### **3.3.3.4.8 Oven spring (cm)**

The differences in the height of dough just before and after baking was used to determine the oven spring of the bread as described by Shittu *et al.* (2008)

#### **3.3.3.4.9 Puffiness (%)**

Percentage puffiness was determined by following the methods as described by Nammakuna *et al.* (2010). Percentage puffiness was calculated as given below;

$$\% \text{age puffiness} = \frac{\text{Thickness of baked bread} - \text{Thickness of bread dough}}{\text{Thickness of breads dough}} \times 100$$

#### **3.3.3.4.10 Yield (%)**

The yield of developed flat breads was measured using a digital balance ( $\pm 0.01$  g accuracy). The yield was then calculated by using the following equation:

$$\text{Yield (g)} = \frac{\text{Weight of flat breads (g)}}{\text{Weight of ingredients (g)}} \times 100$$

### **3.3.4 Optimization of processing conditions for development of low gluten flat breads.**

Numerical optimisation was performed with the help of statistical software Design-Expert 12 (Stat-Ease Inc. Minneapolis, MN, USA). The optimization was carried out under following constraints: Hardness, cohesiveness, springiness, Gumminess, chewiness, overall acceptability,  $L^*$ ,  $a^*$ ,  $b^*$ . Spread ratio (W/T), Volume index Thickness, Weight, Width, Specific volume, Oven spring, Puffiness and Yield. The optimization was carried out under following constraints: maximize Springiness, cohesiveness, spread ratio, volume index, puffiness, yield and  $L^*$  and minimize Hardness, Gumminess, chewiness, thickness, width and  $a^*$  and  $b^*$ . The software was used to generate optimum processing conditions and to predict the corresponding responses as well

### **3.3.5 Physicochemical characteristics of low gluten flat bread.**

The low-gluten flat bread obtained after following the optimized processing conditions were evaluated for below mentioned physicochemical attributes.

**3.3.5.1 Moisture content (%)**. As described at 3.2.1.1

**3.3.5.2 Ash (%)**. As described at 3.2.1.2

**3.3.5.3 Crude Protein (%)**. As described at 3.2.1.3

**3.3.5.4 Crude Fibre (%)**. As described at 3.2.1.4

**3.3.5.5 Crude Fat (%)**. As described at 3.2.1.5

**3.3.5.6 Carbohydrates (%)**. As described at 3.2.1.6

**3.3.5.7 Total Sugars (%)** As described at 3.2.1.7

**3.3.5.8 (Reducing and non-reducing sugars) (%)** As described at 3.2.1.8 and 3.2.1.9

**3.3.5.9 Gluten % of flour blend** As described at 3.2.1.15

**3.3.5.10 Resistant starch(%)** As described at 3.2.1.10

**3.3.5.11 Total starch(%)** As described at 3.2.1.11

**3.3.5.12 Amylose(%)** As described at 3.2.1.12

**3.3.5.13. Amylopectin (%)** As described at 3.2.1.13

**3.3.5.14. Damaged starch (%)** As described at 3.2.1.14

**3.3.5.15 Mineral profile (mg/100g)** As described at 3.2.1.17

**3.3.5.16 Farinographic characteristics** As described at 3.2.3

**3.3.5.17 Pasting properties** As described at 3.2.2.1

**3.3.5.19 Texture Profile Analysis** As described at 3.3.3.1

**3.3.5.20 Sensory evaluation**

Flat bread samples were evaluated for sensory attributes (appearance, colour, texture, flavor, chewability, mouthfeel and overall acceptability) through a panel of ten semi-trained judges using 5-point hedonic scale which was ranging from 1 (poor) to 5 (excellent). The proforma given in Appendix III was used for sensory evaluation by ten semi-trained panelists from Division of Food Science and Technology, SKUAST-K.

**3.3.5.21 Bread parameters.** As described at 3.3.3.4

**3.4 Effect of hydrocolloids on the optimized quality and stability of local flat breads.**

Optimized flat bread was incorporated with three different hydrocolloids SSL (sodium stearoyl-2-lactylate), Guar gum. and CMC (carboxymethyl cellulose) at a concentration of 0.3 to 0.9% and were analysed for following parameters:

### **3.4.1 Proximate composition**

**3.4.1.1 Moisture content (%)**. As described at 3.2.1.1

**3.4.1.2 Ash (%)**. As described at 3.2.1.2

**3.4.1.3 Crude Protein (%)**. As described at 3.2.1.3

**3.4.1.4 Crude Fibre (%)**. As described at 3.2.1.4

**3.4.1.5 Crude Fat (%)**. As described at 3.2.1.5

**3.4.1.6 Carbohydrates (%)**. As described at 3.2.1.6

**3.4.2 Texture profile Analysis**. As described at 3.3.3.1

**3.4.3 Instrumental colour**. As described at 3.3.3.3

**3.4.4 Bread parameters**. As described at 3.3.3.4

### **3.4.5 Degree of staling - Fourier Transform Infrared (FT-IR) Spectroscopy**

Degree of staling was elucidated by FT-IR analysis. FT-IR analysis was carried out following the methods of Mir *et al.* (2015). About 2 mg of properly dried sample was thoroughly mixed with 50 mg desiccated potassium bromide powder in mortar and pestle before pressing into a thin pellet. The infrared absorption spectra of the sample were obtained using an FTIR spectrometer (Thermo Nicolet 6700, Thermoscientific, UK). The equipment was operated with a resolution of  $0.1\text{ cm}^{-1}$  and scanning range of  $4000\text{-}450\text{ cm}^{-1}$ .

### **3.4.6 Sensory evaluation**

Flat breads were evaluated for sensory attributes (appearance, colour, flavor, texture, Hardness, staling and overall acceptability) through a panel of ten semi-trained judges using 5-point Hedonic scale which was ranging from 1 (poor) to 5 (excellent). The proforma given in Appendix III was used for sensory evaluation by ten semi-trained panelists from Division of Food Science and Technology, SKUAST-K.

### **3.5 Storage stability studies of low gluten flat breads.**

Low gluten flat breads were packed in metalized polyester (Met-PE) and stored for 10 days under the following conditions:

- Storage conditions : (a) Ambient (25-30±2°C)  
(b) Accelerated (38±2°C) (75-80% RH)

Evaluation was carried out at an interval of 2 days for the following parameters:

#### **3.5.1 Water Activity (aw)**

Water activity of samples was determined using a water activity meter (PRE AQUA LAB, Water Activity Analyser, SN (PRE 000197).

**3.5.2 Moisture Content (%).** As described at 3.2.1.1

**3.5.3 Instrumental colour.** As described at 3.3.3.3

**3.5.4 Resistant starch (%).** As described at 3.2.1.10

**3.5.5 Total Starch (%).** As described at 3.2.1.11

**3.5.6 Spread factor ratio (W/T).** As described at 3.3.3.4.1

**3.5.7 Texture profile analysis.** As described at 3.3.3.1

**3.5.18 Degree of staling.** As described at 3.4.5

#### **3.5.9 Visual mold growth**

Visual mold growth was observed by naked eye.

#### **3.5.10 Free Fatty Acids (%oleic acid)**

Standard AOAC procedure (2005) was followed for free fatty acid determination of flat breads with slight modification. Product sample (5 g) was taken in flask and 50 mL benzene was added and kept for 30 minutes for extraction of free fatty acids. After extraction, 5mL extract, 5 mL benzene, 10 mL alcohol and phenolphthalein as indicator was taken in flask and titrated against

0.02 N KOH till pink colour disappeared. The fatty acid value was calculated by using the equation given below:

$$\text{Fatty acid value as \%oleic acid} = \frac{28.2 \times \text{titrant value} \times \text{Normality}}{1000 \times \text{Weight of samples (g)}} \times 100$$

**3.5.11 Sensory evaluation.** As described at 3.4.6.

### **3.6 Statistical analysis**

Statistical analysis of the data was conducted using SPSS software (version 21). All the experiments were carried out in triplicates and data was expressed as mean±standard deviation. The results obtained for all the parameters were statistically analysed by employing paired Students t test. The statistical difference was determined with *p* value <0.01. For storage experiment two-factorial CRD was used to analyse the data at 5% level of significance using Duncan's Multiple Range Test (DMRT).

## Chapter-4

### EXPERIMENTAL FINDINGS

The present investigation entitled “Development of rice flour incorporated wheat based low gluten shelf stable kashmiri flat bread” was carried out in the Division of Food Science and Technology, SKUAST-K, Shalimar, Kashmir. The results obtained during investigation are presented as under:

#### **4.1 Experiment I : Evaluation of the physico-chemical properties of raw materials (Refined wheat flour and Rice flour)**

The proximate composition of refined wheat flour and rice flour was determined and data is presented in Table 4.1 . Two flours differed considerably from one another with respect to various physicochemical characteristics. The highest moisture content of (11.12%) was noticed in refined wheat flour followed by rice flour (10.27%). Refined wheat flour possessed highest content of crude protein (11.42%), crude fat (0.68%), crude fibre (1.32%) and ash (0.65%). While as, rice flour contained highest carbohydrate content (79.84%) and lowest crude protein (7.84)%, crude fat (0.49%), crude fibre (0.51%) and ash percentage (0.55%). Further, refined wheat flour exhibited higher reducing (1.19%), non-reducing sugars (4.14) and therefore higher total sugars (5.33%) than rice flour. Rice flour had higher falling number (550.00sec). Also the results revealed that rice flour had the lesser amylose content (16.5%), higher total starch (75.15%) whereas, damaged starch (11.80%) and resistant starch (4.15%) was higher in refined wheat flour. Wet and dry gluten contents of refined wheat flour were (28.20%) and (10.28%), respectively whereas, rice flour was observed to be lacking in gluten.

**Table 4.1: Physicochemical characteristics of refined wheat and rice flour**

<b>Parameters</b>	<b>Refined wheat flour</b>	<b>Rice flour</b>
<b>Physical properties</b>		
Moisture (%)	11.12±0.02	10.27±0.01
<b>Chemical properties</b>		
Crude fat (%)	0.68±0.05	0.49±0.03
Crude protein (%)	11.42±0.03	7.84±0.04
Ash (%)	0.65±0.03	0.55±0.04
Crude fiber (%)	1.32±0.04	0.51±0.03
Carbohydrates (%)	74.81±1.12	79.84 ±1.57
Total sugars (%)	5.33±0.43	1.82±0.11
Reducing sugars (%)	1.19±0.19	0.26±0.05
Non reducing sugars (%)	4.14±0.36	1.56±0.13
(Falling number) (sec)	438.00±4	550.00±5
<b>In vitro starch digestibility</b>		
Amylose (%)	23.03±1.17	16.5±1.10
Amylopectin (%)	76.97±2.56	83.41±2.87
Total starch (%)	68.92±1.65	75.15±1.30
Resistant starch (%)	4.15±0.58	3.12±0.35
Damaged starch(%)	11.80±0.75	8.01±0.60
<b>Gluten content</b>		
Wet gluten(%)	28.20±1.12	0.03±0.01
Dry gluten (%)	10.28±0.74	0.01±0.00

Values are presented as mean±standard deviation

#### 4.1.1 Mineral profile of wheat and rice flour

Table 4.2 shows the mineral profile of wheat flour and rice flour. Analysis of data revealed that rice flour contained higher content of sulphur ( $66.60 \pm 2.20$  mg/100g), phosphorous ( $148.51 \pm 3.00$  mg/100g) whereas, higher content of iron ( $2.15 \pm 0.90$  mg/100g), zinc ( $2.92 \pm 1.50$  mg/100g), calcium ( $18.12 \pm 1.80$  mg/100g) and sodium ( $4.85 \pm 1.20$  mg/100g), was observed in wheat flour

**Table 4.2: Mineral profile of wheat and rice flour**

Parameters	Refined wheat flour	Rice flour
Calcium (mg/100g)	$18.12 \pm 1.80$	$6.53 \pm 0.09$
Sodium (mg/100g)	$4.85 \pm 1.20$	$3.92 \pm$
Sulphur (mg/100g)	$63.00 \pm 2.00$	$66.60 \pm 2.20$
Phosphorous (mg/100g)	$88.30 \pm 2.24$	$148.51 \pm 3.12$
Iron (mg/100g)	$2.15 \pm 0.10$	$1.26 \pm 0.40$
Zinc (mg/100g)	$2.92 \pm 0.89$	$1.60 \pm 0.60$

Values are presented as mean  $\pm$  standard deviation

#### 4.1.2 Pasting properties of wheat and rice flour

The results of pasting properties of refined wheat flour and rice flour are depicted in Table 4.3 Analysis of data indicated that all the pasting properties were significantly ( $p < 0.01$ ) higher in rice flour except pasting temperature. Peak viscosity ( $2032.00 \pm 2.63$ cp), Hold viscosity ( $1614.00 \pm 1.88$ cp), breakdown viscosity ( $491.00$ cp), final viscosity ( $2585 \pm 2.21$ cp) and setback viscosity ( $972.00 \pm 2.68$ ) were found to be higher in rice flour. Pasting temperature ( $86.15 \pm 1.70^\circ\text{C}$ ) and pasting time ( $7.02 \pm 0.02$  min) were higher in refined wheat flour.

**Table 4.3: Pasting Properties of wheat and rice flour**

Parameter	Refined wheat flour	Rice flour
Pasting Time (min)	7.02±0.02	6.73±0.01
Peak Viscosity (cP)	1675.00±1.44	2032.00±2.63
Hold Viscosity (cP)	1290.00±1.63	1614.00±1.88
Setback Viscosity (cP)	808.00±1.76	972.00±2.68
Final Viscosity (cP)	2098.00±2.92	2585±2.21
Breakdown Viscosity (cP)	385.00±1.51	491.00±1.80
Pasting Temperature (°C)	86.15±1.70	80.33±1.96

\* Values are presented as mean±standard deviation

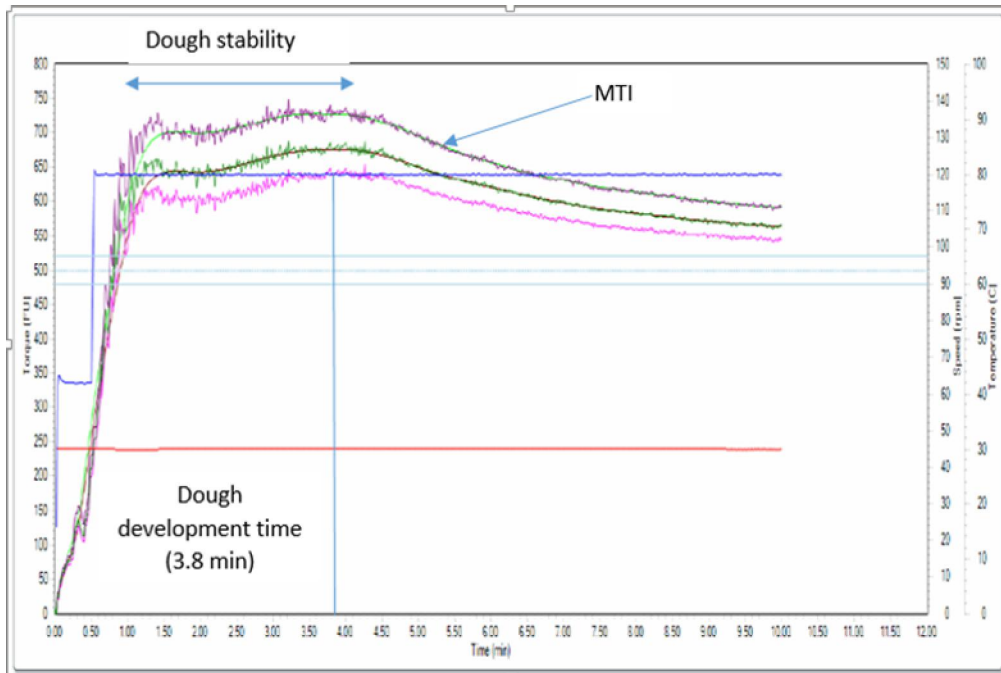
#### 4.1.3 Farinographic properties

Farinographic properties of refined wheat flour and rice flour are presented in Table 4.4 and Fig. 4.1a and b. the arrival time (8.70±0.21min), Degree of softening (55.00±0.51BU), water absorption capacity (62.31±2.42%) and dough development time (10.0±1.67 min) were significantly ( $p<0.01$ ) higher in rice flour whereas, dough stability values (4.8±0.13 min) and mixing tolerance index (125.2±4.52 BU) were significantly ( $p<0.01$ ) higher in refined wheat flour.

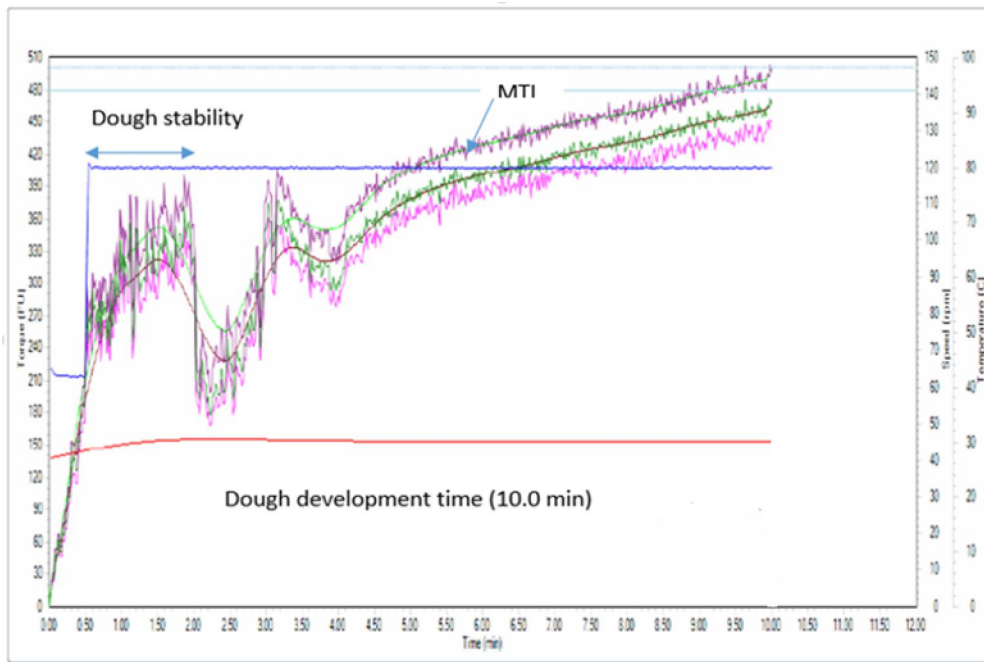
**Table 4.4: Farinographic characteristics of wheat and rice flour**

Parameter	Refined wheat flour	Rice Flour
Arrival Time (min)	1.5±0.12	8.70±1.17
Degree of softening(BU)	40.00±2.11	55.00±2.23
Water absorption capacity (%)	60.20±2.30	62.31±2.41
Dough development time (min)	3.80±1.12	10.00±1.19
Dough Stability (min)	4.80±1.16	1.78±0.23
Mixing Tolerance index (BU)	60.20±3.12	20.00±2.19

\*Values are presented as mean±standard deviation



a



b

Fig. 4.1: Farinographic parameters of (a) wheat flour and (b) rice flour

## **4.2 Experiment II: Process optimization for the development of rice flour incorporated wheat based flat bread.**

### **4.2.1 Model fitting**

Response Surface Methodology (RSM) software Design-Expert 12 was used to investigate the effects of processing conditions on product characteristics. The independent variables included the feed proportion i.e. Rice : wheat flour (0:100 to 55:45); Mixing time (2 -10 min); Fermentation time (30-70 min) and Baking temperature (250-300 °C). Dependent variables were texture profile analysis (TPA), sensory evaluation (overall acceptability) , instrumental colour ( $L^*$ ,  $a^*$ ,  $b^*$ ) and bread parameters.(spread ratio, volume index, Weight, width, thickness, specific volume, oven spring percentage puffiness (%) and yield (%). Highly significant ( $p < 0.001$ ) models having coefficient of determination ( $R^2$ ) in the range of 0.92 -0.99 were recorded in the selected dependent variables (Table 4.5). Predicted and adjusted  $R^2$  values were in reasonable agreement with each other in all the dependent variables. Coefficient of variation and adequate precision were found in the range of 0.06-4.25% and 17.73-466.70 respectively. In all the dependent variables lack of fit was found to be non-significant.

**Table 4.5: Analysis of variance for the fit of experimental data to response surface models**

Term	HD	SPR	COH	GUM	CHEW	WD	THC	S.R	WT	V.I	S.V	Puff.	O.S	L*	a*	b*	OAA	Yield
F-value	81.81	13.61	19.98	104.14	61.21	163.00	184.63	1417.57	3842.57	50.97	862.91	19.46	148.18	5329.37	96.67	18.90	70.88	10464.77
P > F	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
CV (%)	1.70	1.73	1.85	3.17	4.25	0.10	0.07	0.10	0.10	0.52	0.45	4.17	0.36	0.10	3.83	3.75	0.82	0.06
R <sup>2</sup>	0.9871	0.9270	0.9491	0.9898	0.9828	0.9935	0.9998	0.9798	0.9697	0.9794	0.9988	0.9478	0.9928	0.997	0.9897	0.9464	0.9851	0.9998
Adjusted R <sup>2</sup>	0.9750	0.8589	0.9016	0.9803	0.9667	0.9874	0.9999	0.9895	0.9995	0.9602	0.9976	0.8891	0.9861	0.9996	0.9788	0.8963	0.9712	0.9998
Predicted R <sup>2</sup>	0.9387	0.7606	0.7157	0.9578	0.9192	0.9698	0.9997	0.9996	0.9986	0.8903	0.9926	0.8029	0.9634	0.9991	0.9436	0.7614	0.9167	0.9995
Adequate precision	40.518	119.375	23.967	46.155	34.789	56.273	568.161	520.751	279.010	31.54	134.097	19.368	53.154	332.730	44.116	19.858	38.067	466.702
Lack of fit	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

The abbreviated terms given in the table stand for:

HD: Hardness, SPR: Springiness, COH: cohesiveness, GUM: Gumminess, CHEW: chewiness,

WD: width ; THCK: Thickness ;SR: spread ratio ; WT; Weight ; VI; volume index ; SV: specific volume ; PUFF: puffiness ; OS : Oven spring;; L\* :lightness; a\* :redness; b\*: yellowness; OAA; Overall acceptability

## 4.2.2 Effect of independent variables of processing conditions on dependent variables/parameters

### 4.2.2.1 Texture profile Analysis of low gluten flat bread (LGFB)

#### 4.2.2.1.1 Hardness (H)

Hardness of LGFB varied from 8.03 to 12.29N (Table 4.6a). The significant ( $p < 0.05$ ) predicted model obtained for hardness (H) from regression analysis is given in equation (4.1) provided below;

$$H = 9.32 - 1.06A - 0.095B - 0.097C + 0.173A^2 + 0.094B^2 \dots 4.1$$

The fitted regression equation (4.1) shown above and response surface plots (Fig. 4.2) indicate that with the increase in rice flour composition (A), mixing time (B) and fermentation time (C) the hardness was decreased significantly, Table 4.6a indicates that the linear effects of feed composition (A), mixing time (D) and fermentation time (C) had significant effects on hardness. Also, the quadratic effects of feed composition ( $A^2$ ) and mixing time ( $B^2$ ) had significant effects on hardness (Table 4.7)

#### 4.2.2.1.2 Springiness (SPR)

The Springiness of LGFB varied from 0.68 to 0.86 mm (Table 4.6a). The predicted model obtained from regression analysis for springiness was developed as follows

$$SPR = 0.72 + 0.01A + 0.04C - 0.03AB - 0.059AC + 0.07C^2 \dots 4.2$$

The fitted regression equation (4.2) shown above and response surface plots (Fig. 4.3) indicates that with the increase in rice flour in feed composition (A) and fermentation time (C) the SPR increased significantly. Table 4.8 indicates that the linear effects of feed proportion (A) and fermentation time (C) had significant effects on SPR. Also SPR was significantly affected by the interactive effect of feed composition (A) and mixing time (B) and feed composition (A) and fermentation time (C) as well as by quadratic effects of feed composition ( $A^2$ ). (Table 4.8).

**Table 4.6a: Effect of independent parameters on physicochemical properties of low-gluten flat bread**

S. No.	FC RF:WF	MT (min)	FT (min)	BT (°C)	HD (N)	SPR (mm)	COH	GUM(N)	CHEW(N)	WD (mm)	THC (mm)	SR	Wt(g)
1	25:75	6	30	275	9.83	0.74	0.67	7.66	6.1	133	8	15.4	55.01
2	15:85	8	60	262	10.52	0.75	0.72	8.83	7.32	135	7.63	16.78	52.94
3	40:60	4	40	262	8.61	0.74	0.67	5.59	4.13	132	8.76	14.42	59.11
4	15:85	4	40	287	10.89	0.71	0.62	9.47	6.72	134.8	7.46	16.7	52.93
5	25:75	6	50	250	9.79	0.72	0.66	7.34	5.5	133.5	8.43	15.39	55.26
6	15:85	8	60	287	10.44	0.79	0.7	8.45	6.84	134.9	8.57	16.8	53.15
7	25:75	6	50	275	9.35	0.73	0.66	7.29	5.32	133.2	8.06	14.7	55.2
8	55:45	6	50	275	8.03	0.76	0.62	5.35	4.08	131.8	9	14.68	63.68
9	25:75	2	50	275	9.96	0.71	0.7	7.47	5.52	133.3	8.03	15.39	55.01
10	0:100	6	50	275	12.29	0.71	0.52	11.67	8.4	137.9	6.03	19.87	50.73
11	15:75	8	40	287	10.58	0.71	0.64	8.87	6.2	134.7	7.45	16.7	52.93
12	15:75	4	60	262	10.74	0.77	0.7	9.12	6.38	134.8	7.5	16.76	52.92
13	40:60	8	40	262	8.47	0.75	0.64	5.84	4.02	132	8.86	14.4	58.83
14	25:75	6	50	275	9.39	0.73	0.66	7.13	5.2	133.5	8.63	14.8	55.29
15	40:60	4	60	262	8.69	0.78	0.71	5.82	4.53	132.3	8.8	14.48	58.84

Contd....

Table 6a: contd....

S. No.	FC RF:WF	MT (min)	FT (min)	BT (°C)	HD (N)	SPR (mm)	COH	GUM(N)	CHEW(N)	WD (mm)	THC (mm)	SR	Wt(g)
16	15:85	4	40	262	10.94	0.68	0.6	9.08	6.26	134.6	7.53	16.79	52.92
17	15:85	4	60	287	10.66	0.79	0.7	8.95	7.07	134.5	7.46	16.7	52.94
18	25:85	6	70	275	9.24	0.86	0.76	7.11	5.8	133.7	8.02	15.62	55.06
19	40:60	4	60	287	8.55	0.78	0.71	5.55	4.32	132.2	8.78	14.46	58.82
20	15:75	8	40	262	10.82	0.73	0.64	8.65	6.31	134.6	7.5	16.77	52.97
21	40:60	8	60	287	8.19	0.73	0.66	5.15	3.75	132.4	9	14.48	58.88
22	25:75	10	50	275	9.88	0.74	0.68	7.41	5.33	133.7	8.1	15.39	55.09
23	40:60	8	60	262	8.23	0.75	0.68	5.43	3.9	132.3	9.02	14.4	58.85
24	25:75	6	50	275	9.48	0.74	0.68	6.63	4.77	133.5	8.63	14.82	55.25
25	25:75	6	50	300	9.27	0.72	0.65	6.85	4.93	133.3	8.34	15.39	55.13
26	25:75	6	50	275	9.59	0.71	0.66	7.28	5.31	133.5	8.63	14.82	55.19
27	40:60	4	40	287	8.59	0.75	0.7	5.32	4.04	132.1	8.75	14.33	58.85
28	25:75	6	50	275	9.67	0.73	0.66	7.15	3.45	133.4	8.63	14.82	55.25
29	40:60	8	40	287	8.34	0.74	0.67	5.08	5.45	132.3	8.82	14.33	58.83
30	25:75	6	50	275	9.74	0.72	0.65	7.2	3.48	133.6	8.64	14.8	55.27

FC: Feed comp.; RF:WF(Rice flour : wheat flour) ; MT: Mixing Time; FT: Fermentation time:

BT:Baking Temp., HD: Hardness, SPR: Springiness. COH: cohesiveness, GUM: Gumminess, CHEW: chewiness,

WD: width ; THCK: Thickness ;SR: spread ratio ; WT; Weight ; VI; volume index ; SV: specific volume ; PUFF: puffiness ; OS : Oven spring;; L\* :lightness; a\* :redness; b\*: yellowness; OAA;Overallacceptability.

**Table 4.6b: Effect of independent parameters on physicochemical properties of low-gluten flat bread**

S. No.	FC RF:WF	MT (min)	FT (min)	BT (°C)	VI(cm)	SV (cm <sup>3</sup> /g)	PUFF (%)	O.S (cm)	L*	a*	b*	OAA	Yield (%)
1	25:75	6	30	275	1.65	4.81	44.2	1.6	45.41	3.48	29.84	3.73	134.2
2	15:85	8	60	262	1.72	5.25	46.9	1.68	43.89	4.03	32.32	3.51	132.4
3	40:60	4	40	262	1.6	4.25	35.5	1.55	48.28	2.56	26.85	3.93	137.38
4	15:85	4	40	287	1.7	5.2	46.81	1.64	43.24	4.38	32.81	3.58	132.3
5	25:75	6	50	250	1.66	4.82	44.3	1.62	45.73	3.12	29.31	3.64	134.5
6	15:85	8	60	287	1.71	5.24	46.83	1.69	43.75	4.09	32.43	3.52	132.4
7	25:75	6	50	275	1.67	4.84	44.5	1.63	45.48	4.17	29.39	3.65	134.4
8	55:45	6	50	275	1.57	3.8	24.33	1.51	51.37	1.99	24.11	4.2	140.58
9	25:75	2	50	275	1.66	4.83	44.4	1.61	45.36	4.63	29.89	3.72	134.3
10	0:100	6	50	275	1.75	5.79	53.1	1.73	40.34	4.82	33.85	3.3	129.49
11	15:75	8	40	287	1.7	5.21	46.8	1.65	43.65	4.2	32.55	3.54	132.3
12	15:75	4	60	262	1.72	5.23	46.8	1.65	43.54	4.25	32.59	3.55	132.4
13	40:60	8	40	262	1.62	4.27	35.6	1.56	48.63	2.27	27.49	3.89	137.5
14	25:75	6	50	275	1.68	4.85	44.6	1.63	45.51	3.24	29.47	3.66	134.4
15	40:60	4	60	262	1.62	4.26	35.7	1.55	48.47	2.41	27.66	3.91	137.5

Contd....

Table 6b: contd....

S. No.	FC RF:WF	MT (min)	FT (min)	BT (°C)	VI(cm)	SV (cm <sup>3</sup> /g)	PUFF (%)	O.S (cm)	L*	a*	b*	OAA	Yield (%)
16	15:85	4	40	262	1.7	5.23	46.8	1.65	43.31	4.34	32.75	3.57	132.4
17	15:85	4	60	287	1.69	5.24	46.8	1.67	43.42	4.29	32.67	3.56	132.3
18	25:85	6	70	275	1.7	4.86	44.8	1.65	45.67	3.54	29.76	3.75	134.42
19	40:60	4	60	287	1.61	4.28	35.8	1.57	48.39	2.49	27.76	3.92	137.4
20	15:75	8	40	262	1.7	5.25	46.7	1.65	43.74	4.15	32.49	3.53	132.3
21	40:60	8	60	287	1.62	4.29	35.9	1.59	48.79	2.19	27.37	3.88	137.5
22	25:75	10	50	275	1.69	4.87	44.7	1.64	45.97	3.09	29.79	3.74	134.44
23	40:60	8	60	262	1.63	4.27	35.9	1.57	48.88	2.13	27.29	3.87	137.55
24	25:75	6	50	275	1.68	4.86	44.9	1.63	45.53	3.29	29.56	3.67	134.4
25	25:75	6	50	300	1.66	4.87	46.69	1.64	45.46	3.41	29.73	3.71	134.3
26	25:75	6	50	275	1.67	4.87	44.9	1.63	45.56	3.34	31.25	3.68	134.4
27	40:60	4	40	287	1.6	4.27	35.7	1.54	48.19	2.65	27.91	3.94	137.2
28	25:75	6	50	275	1.67	4.87	44.9	1.63	45.58	3.36	29.62	3.69	134.4
29	40:60	8	40	287	1.6	4.29	35.7	1.55	48.56	2.34	27.58	3.9	137.36
30	25:75	6	50	275	1.68	4.87	50	1.62	45.59	3.38	29.67	3.7	134.35

FC: Feed comp.: RF:WF(Rice flour : wheat flour) ; MT: Mixing Time: FT: Fermentation time:

BT:Baking Temp., HD: Hardness, SPR: Springiness. COH: cohesiveness, GUM: Gumminess, CHEW: chewiness,

WD: width ; THCK: Thickness ;SR: spread ratio ; WT; Weight ; VI; volume index ; SV: specific volume ; PUFF: puffiness ; OS : Oven spring;; L\* :lightness; a\* :redness; b\*: yellowness; OAA;Overallacceptability.

**Table 4.7: Regression coefficient and model statistics for Hardness (H)**

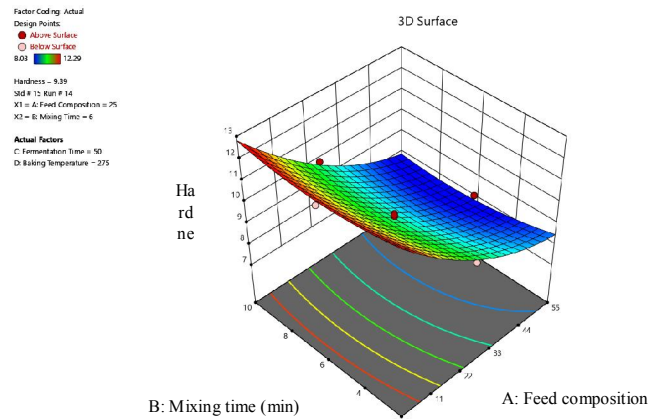
Source	Coefficient Estimate	Sum of Squares	Df	Standard error	F-value	p-value Prob >F
<b>Model</b>	9.32	30.51	14	0.0674	81.81	< 0.0001***
A-Feed Composition	-1.06	29.14	1	0.0707	1093.90	< 0.0001***
B-Mixing Time	-0.0910	0.2173	1	0.0669	8.16	0.0120*
C-Fermentation Time	-0.0978	0.2260	1	0.0669	8.48	0.0107*
D-Baking Temperature	-0.1500	0.1337	1	0.0669	5.02	0.0906
AB	-0.1242	0.0129	1	0.1783	0.4853	0.4967
AC	0.1618	0.0219	1	0.1783	0.8232	0.3786
AD	0.0659	0.0036	1	0.1783	0.1365	0.7170
BC	-0.1100	0.0121	1	0.1632	0.4543	0.5106
BD	-0.0444	0.0020	1	0.1632	0.0741	0.7892
CD	0.0216	0.0005	1	0.1632	0.0175	0.8965
A <sup>2</sup>	0.1731	1.11	1	0.1298	41.59	< 0.0001***
B <sup>2</sup>	0.0945	0.2402	1	0.1254	9.02	0.0089**
C <sup>2</sup>	-0.0085	0.0001	1	0.1254	0.0047	0.9465
D <sup>2</sup>	-0.0177	0.0005	1	0.1253	0.0200	0.8895

\*Significant at P<0.05; \*\*Significant at P<0.01; \*\*\*Significant at P<0.001

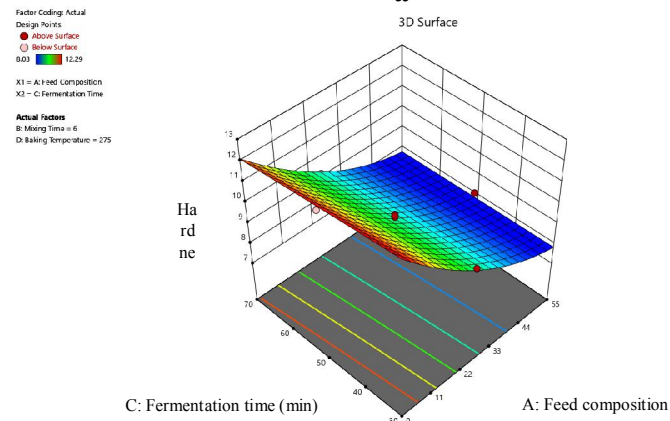
**Table 4.8: Regression coefficient and model statistics for Springiness (SPR)**

Source	Coefficient Estimate	Sum of Squares	Df	Standard error	F-value	p-value Prob >F
<b>Model</b>	0.7283	0.0315	14	0.0053	13.61	< 0.0001***
A-Feed Composition Rice: Wheat	0.0169	0.0015	1	0.0056	9.26	0.0082**
B-Mixing Time	-0.0004	9.182E-07	1	0.0053	0.0056	0.9415
C-Fermentation time	0.0458	0.0125	1	0.0053	75.63	< 0.0001***
D-baking temperature	0.0033	0.0001	1	0.0053	0.3867	0.5434
AB	-0.0330	0.0009	1	0.0140	5.52	0.0330*
AC	-0.0597	0.0030	1	0.0140	18.06	0.0007***
AD	-0.0232	0.0004	1	0.0140	2.72	0.1197
BC	-0.0375	0.0014	1	0.0128	8.52	0.3206
BD	-0.0170	0.0003	1	0.0128	1.75	0.2054
CD	0.0079	0.0001	1	0.0128	0.3735	0.5503
A <sup>2</sup>	0.0074	0.0001	1	0.0102	0.5234	0.4805
B <sup>2</sup>	-0.0010	1.564E-06	1	0.0099	0.0095	0.9238
C <sup>2</sup>	0.0740	0.0093	1	0.0099	56.26	< 0.0001***
D <sup>2</sup>	-0.0062	0.0001	1	0.0099	0.3921	0.5406

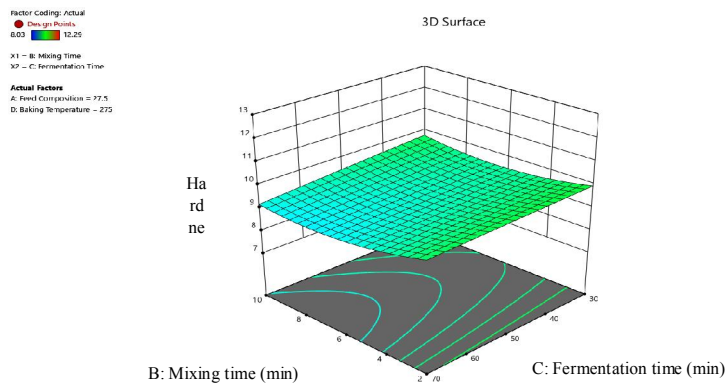
\*Significant at P<0.05; \*\*Significant at P<0.01; \*\*\*Significant at P<0.001



**a**



**b**



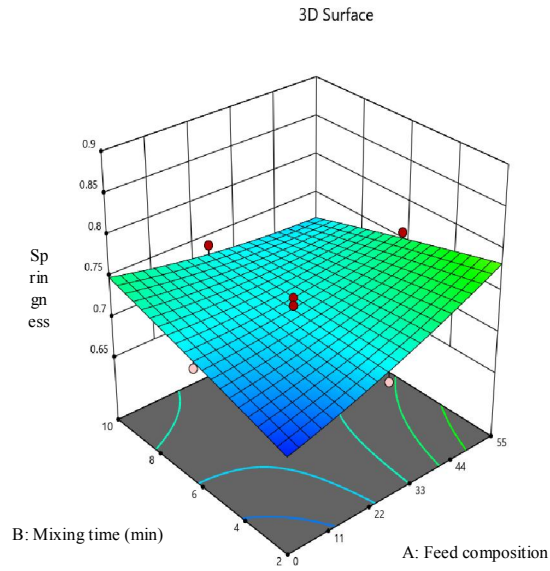
**c**

**Fig. 4.2:** Effect of independent variables on Hardness (H) of low-gluten flat breads (a): feed composition and mixing time on H (b): feed composition and fermentation time on H (c): mixing time and fermentation time on H.

Factor Coding: Actual  
 Design Points  
 ● Above Surface  
 ○ Below Surface  
 0.68 0.86

X1 = A: Feed Composition  
 X2 = B: Mixing Time

**Actual Factors**  
 C: Fermentation Time = 50  
 D: Baking Temperature = 275

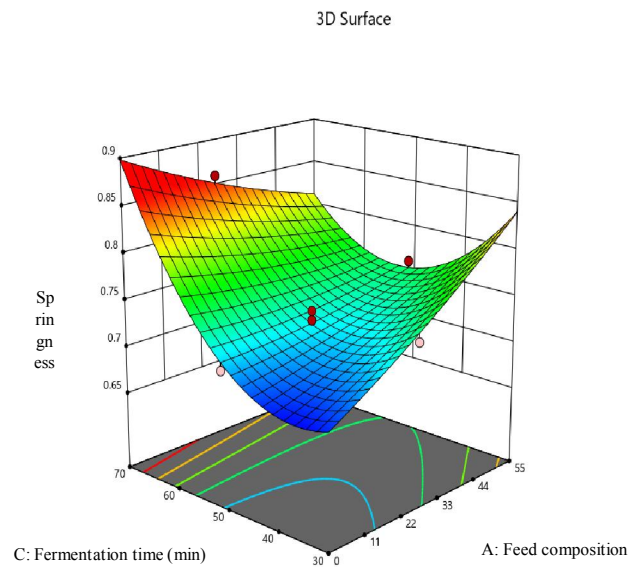


**a**

Factor Coding: Actual  
 Design Points  
 ● Above Surface  
 ○ Below Surface  
 0.68 0.86

X1 = A: Feed Composition  
 X2 = C: Fermentation Time

**Actual Factors**  
 B: Mixing Time = 6  
 D: Baking Temperature = 275



**b**

**Fig. 4.3:** Effect of independent variables on Springiness (SPR) of low-gluten flat breads (a): feed composition and mixing time on SPR (b): feed composition and fermentation time on SPR

#### 4.2.2.1.3 Cohesiveness (COH)

The cohesiveness of LGFB varied from 0.52 to 0.76 (Table 4.6a). The predicted model obtained from regression analysis for COH was developed as follows

$$\text{COH} = 0.65 + 0.03A + 0.04C - 0.06AB - 0.05AC + 0.03B^2 + 0.05C^2 \dots\dots 4.3$$

The fitted regression equation (4.3) shown above and response surface plots (Fig. 4.4) indicates that with the increase in rice flour in feed composition (A) and fermentation time (C) the COH was increased significantly. Table 4.9 indicates that the linear effects of feed proportion (A) and fermentation time (C) had significant effects on COH. Also COH was significantly affected by the interactive effect of feed composition (A) and mixing time (B) and feed composition (A) and fermentation time (C) as well as by quadratic effects of mixing time (B)<sup>2</sup> and fermentation time (C)<sup>2</sup>. (Table 4.9).

#### 4.2.2.1.4 Gumminess (Gumm)

The Gumminess of LGFB was found in the range of 5.08 to 11.67 N (Table 4.6a). The significant model representing the Gumminess generated through regression analysis is given as under.

$$\text{Gumm} = 6.77 - 3.75A - 1.26A^2 \dots\dots\dots 4.4$$

The regression equation 4.4 and response surface plots (Fig. 4.5) illustrated that with the increase in feed composition (A), Gumminess was decreased significantly. Table 4.10 indicates that out of different independent variables, only feed composition (A) had significant effects on gumminess and only feed composition (A<sup>2</sup>) had significant quadratic effect on gumminess.

**Table 4.9: Regression coefficient and model statistics for Cohesiveness (COH)**

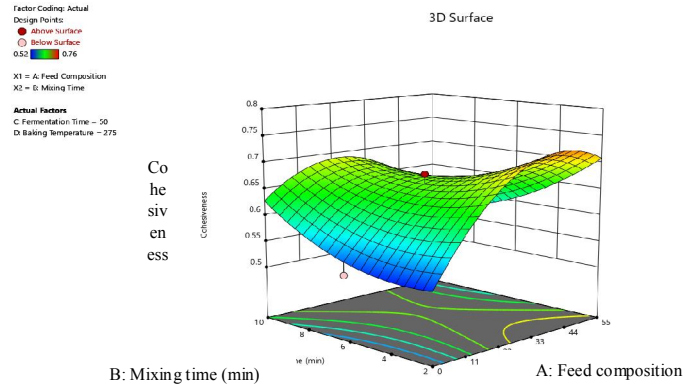
Source	Coefficient Estimate	Sum of Squares	Df	Standard error	F-value	p-value Prob >F
Model	0.6563	0.0575	14	0.0059	19.98	< 0.0001***
A-Feed Composition	0.0371	0.0073	1	0.0062	35.64	< 0.0001***
B-Mixing Time	-0.0089	0.0005	1	0.0059	2.29	0.1509
C-Fermentation Time	0.0444	0.0117	1	0.0059	57.14	< 0.0001***
D-Baking Temperature	0.0019	0.0000	1	0.0059	0.1021	0.7538
AB	-0.0645	0.0035	1	0.0157	16.94	0.0009***
AC	-0.0594	0.0030	1	0.0157	14.41	0.0018***
AD	0.0134	0.0002	1	0.0157	0.7356	0.4046
BC	-0.0150	0.0002	1	0.0143	1.10	0.3119
BD	-0.0203	0.0004	1	0.0143	2.00	0.1774
CD	-0.0352	0.0012	1	0.0143	6.03	0.0767
A <sup>2</sup>	-0.1022	0.0165	1	0.0114	80.32	0.0651
B <sup>2</sup>	0.0331	0.0019	1	0.0110	9.03	0.0089***
C <sup>2</sup>	0.0581	0.0057	1	0.0110	27.84	< 0.0001***
D <sup>2</sup>	-0.0021		1	0.0110	0.0381	0.8478

\*Significant at P<0.05; \*\*Significant at P<0.01; \*\*\*Significant at P<0.001

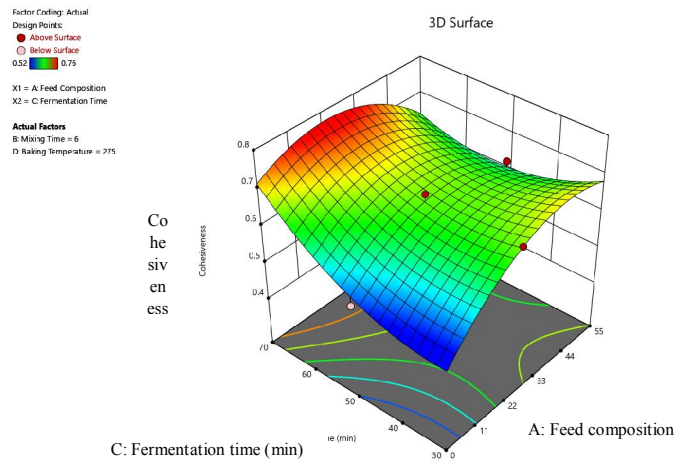
**Table 4.10: Regression coefficient and model statistics for Gumminess (G)**

Source	Coefficient Estimate	Sum of Squares	Df	Standard error	F-value	p-value Prob >F
Model	6.77	77.02	14	0.0949	104.14	< 0.0001***
A-Feed Composition	-3.75	74.98	1	0.0995	1419.45	< 0.0001***
B-Mixing Time	-0.2222	0.2941	1	0.0942	5.57	0.0623
C-Fermentation Time	-0.1362	0.1105	1	0.0942	2.09	0.1687
D-Baking Temperature	-0.2221	0.2931	1	0.0943	5.55	0.0825
AB	0.2389	0.0478	1	0.2511	0.9050	0.3565
AC	0.2564	0.0551	1	0.2511	1.04	0.3235
AD	-0.4326	0.1568	1	0.2511	2.97	0.1054
BC	-0.1400	0.0196	1	0.2298	0.3710	0.5516
BD	-0.2114	0.0447	1	0.2298	0.8468	0.3720
CD	-0.1746	0.0305	1	0.2298	0.5775	0.4591
A <sup>2</sup>	1.26	2.52	1	0.1828	47.77	< 0.0001***
B <sup>2</sup>	0.3465	0.2034	1	0.1766	3.85	0.0685
C <sup>2</sup>	0.2915	0.1440	1	0.1766	2.73	0.1195
D <sup>2</sup>	-0.0011	1.932E-06	1	0.1765	0.0000	0.9953

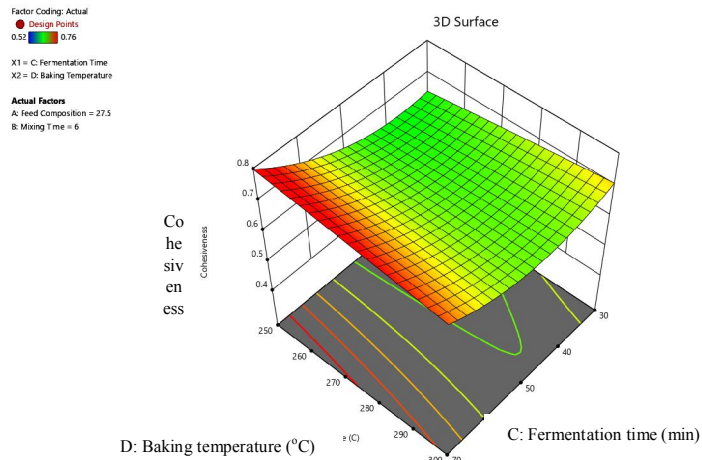
\*Significant at P<0.05; \*\*Significant at P<0.01; \*\*\*Significant at P<0.001



**a**



**b**



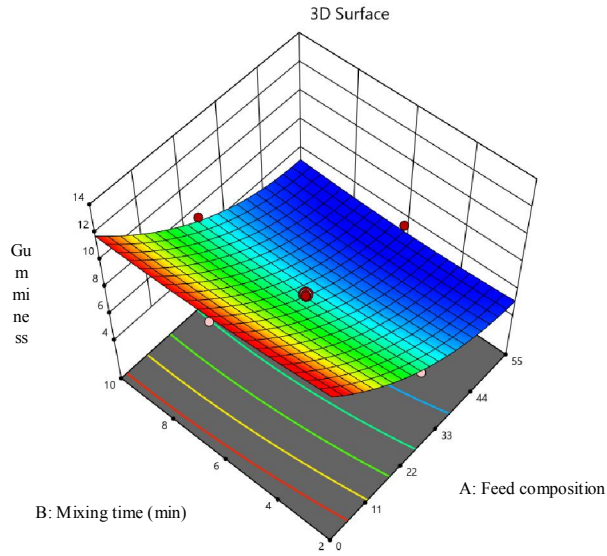
**c**

**Fig. 4.4:** Effect of independent variables on cohesiveness (COH) of low-gluten flat breads (a): feed composition and mixing time on COH (b): feed composition and fermentation time on COH (c): Fermentation time and Baking temperature on COH


Factor Coding: Actual  
 Design Points:  
 ● Above Surface  
 ○ Below Surface  
 5.08  11.67

Gumminess = 7.28  
 Std # 10 Run # 26  
 X1 = A: Feed Composition = 25  
 X2 = B: Mixing Time = 6

**Actual Factors**  
 C: Fermentation Time = 30  
 D: Baking Temperature = 275

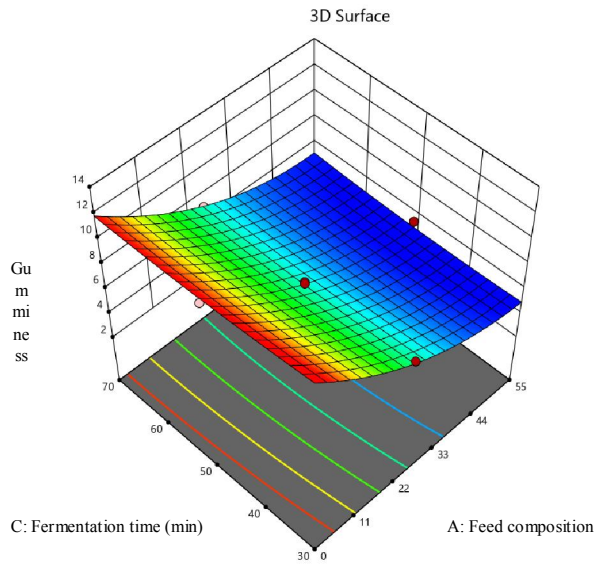


**a**

Factor Coding: Actual  
 Design Points:  
 ● Above Surface  
 ○ Below Surface  
 5.08  11.67

X1 = A: Feed Composition  
 X2 = C: Fermentation Time

**Actual Factors**  
 B: Mixing Time = 6  
 D: Baking Temperature = 275



**b**

**Fig. 4.5:** Effect of independent variables on Gumminess (GUM) of low-gluten flat breads (a): feed composition and mixing time on GUM(b): feed composition and fermentation time on GUM

#### 4.2.2.1.5 Chewiness (CHEW)

The Chewiness of LGFB was found in the range of 3.45 to 8.40 N (Table 4.6a). The significant model representing the chewiness generated through regression analysis is given as under.

$$\text{CHEW} = 4.36 - 2.62A + 1.46A^2 + 1.44C^2 \dots\dots\dots 4.5$$

The regression equation 4.5 and response surface plots (Fig. 4.6) illustrated that with the increase in feed composition (A), Chewiness was decreased significantly. Table 4.11 indicates that out of different independent variables, only feed composition (A) had significant effects on chewiness and only feed composition (A<sup>2</sup>) and fermentation time (C<sup>2</sup>) had significant quadratic effect on chewiness

#### 4.2.2.1.6 Width (W)

The width of LGFB varied from 131.8 to 137.9 mm (Table 4.6a). The predicted model obtained from regression analysis for W was developed as follows.

$$W = 133.17 - 2.89A + 0.14B + 0.223C + 1.66A^2 \dots\dots\dots 4.6$$

The regression equation 4.6 and response surface plots (Fig 4.7) illustrated that with the increase in mixing time (B) and fermentation time (C) bread width increased significantly; whereas with the increase in rice flour composition (A) bread width was decreased significantly.. Table 4.12 indicates that out of different independent variables, except baking temperature (D) all other independent variables had significant linear effects on width of bread samples and only flour composition (A<sup>2</sup>) had positive significant quadratic effect on width of bread samples.

**Table 4.11: Regression coefficient and model statistics for Chewiness (CHEW)**

Source	Coefficient Estimate	Sum of Squares	Df	Standard error	F-value	p-value Prob >F
Model	4.361	44.54	1	0.0942	61.21	< 0.0001***
A-Feed Composition	-2.80	41.92	1	0.0988	806.46	< 0.0001***
B-Mixing Time	-0.1953	0.2271	1	0.0934	4.37	0.0840
C-Fermentation Time	0.3256	0.6313	1	0.0934	12.14	0.0633
D-Baking Temperature	-0.1440	0.1233	1	0.0935	2.37	0.1444
AB	-0.5986	0.3001	1	0.2491	5.77	0.3297
AC	-0.3256	0.0888	1	0.2491	1.71	0.2110
AD	-0.3889	0.1267	1	0.2491	2.44	0.1393
BC	0.1700	0.0289	1	0.2280	0.5559	0.4674
BD	-0.5382	0.2898	1	0.2279	5.57	0.0722
CD	0.0362	0.0013	1	0.2279	0.0252	0.8760
A <sup>2</sup>	0.8261	1.08	1	0.1813	20.75	0.0004***
B <sup>2</sup>	0.2471	0.1034	1	0.1751	1.99	0.1788
C <sup>2</sup>	0.7421	0.9332	1	0.1751	17.95	0.0007***
D <sup>2</sup>	0.0300	0.0015	1	0.1750	0.0294	0.8661

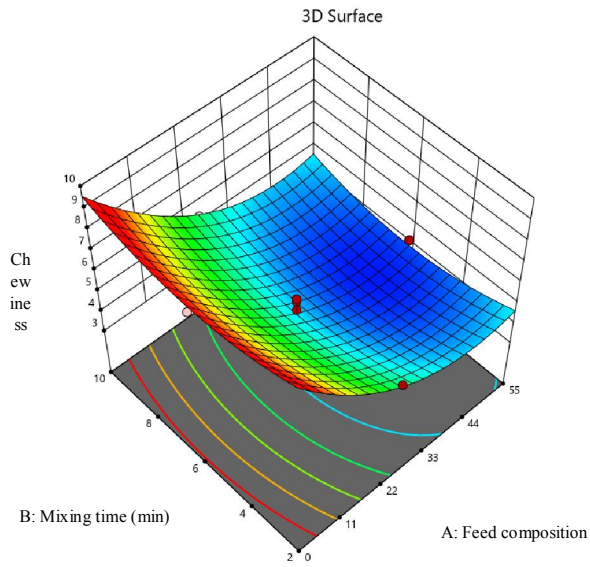
\*Significant at P<0.05; \*\*Significant at P<0.01; \*\*\*Significant at P<0.001

**Table 4.12: Regression coefficient and model statistics for Width (W)**

Source	Coefficient Estimate	Sum of Squares	Df	Standard error	F-value	p-value Prob >F
Model	133.17	48.52	14	0.0602	163.00	< 0.0001***
A-Feed Composition	-2.89	44.49	1	0.0632	2092.51	< 0.0001
B-Mixing Time	-0.1453	0.1203	1	0.0598	5.66	0.0311**
C-Fermentation Time	0.2236	0.2962	1	0.0598	13.93	0.0020**
D-Baking Temperature	-0.1440	0.0002	1	0.0598	0.0078	0.9308
AB	-0.5986	0.0013	1	0.1593	0.0613	0.8079
AC	-0.3256	0.0024	1	0.1593	0.1127	0.7417
AD	-0.3889	0.0182	1	0.1593	0.8556	0.3696
BC	0.1700	0.0306	1	0.1458	1.44	0.2487
BD	-0.5382	0.0162	1	0.1458	0.7611	0.3967
CD	0.0362	0.0728	1	0.1458	3.42	0.0841
A <sup>2</sup>	1.6621	4.37	1	0.1160	205.39	< 0.0001***
B <sup>2</sup>	0.2471	0.0017	1	0.1120	0.0822	0.7783
C <sup>2</sup>	0.7421	0.0236	1	0.1120	1.11	0.3092
D <sup>2</sup>	0.0300	0.0086	1	0.1119	0.4036	0.5348

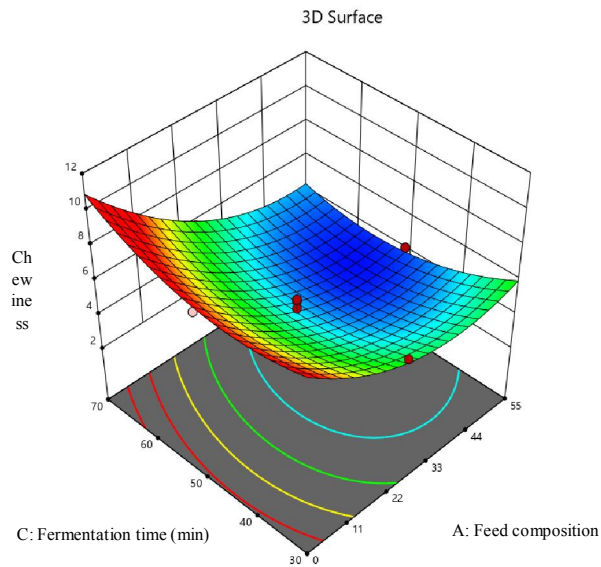
\*Significant at P<0.05; \*\*Significant at P<0.01; \*\*\*Significant at P<0.001

Factor Coding: Actual  
 Design Points:  
 ● Above Surface  
 ○ Below Surface  
 3.45 8.4  
 X1 = A: Feed Composition  
 X2 = B: Mixing Time  
 Actual Factors:  
 C: Fermentation Time = 50  
 D: Baking Temperature = 275



**a**

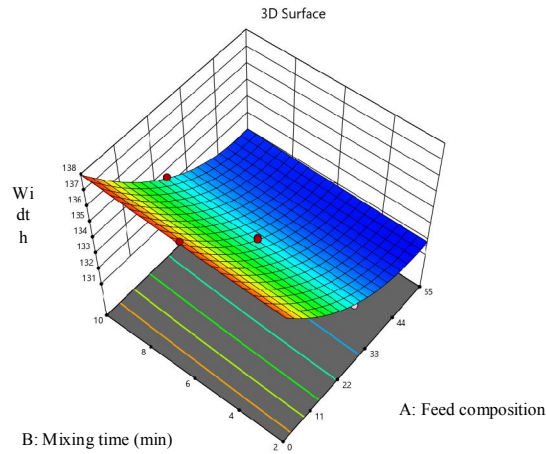
Factor Coding: Actual  
 Design Points:  
 ● Above Surface  
 ○ Below Surface  
 3.45 8.4  
 X1 = A: Feed Composition  
 X2 = C: Fermentation Time  
 Actual Factors:  
 B: Mixing Time = 6  
 D: Baking Temperature = 275



**b**

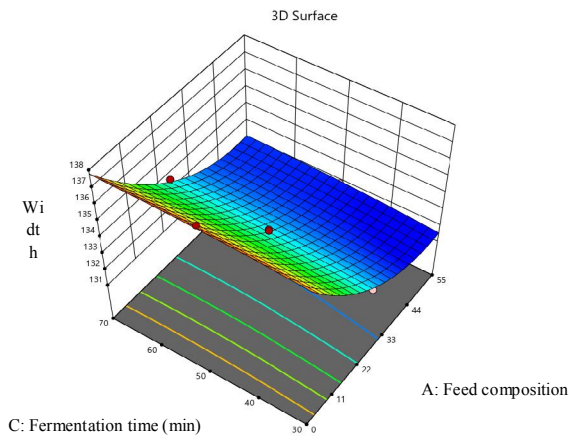
**Fig. 4.6:** Effect of independent variables on Chewiness (CHEW) of low-gluten flat breads (a): feed composition and mixing time on CHEW (b): feed composition and fermentation time on CHEW

Factor Coding: Actual  
 Design Points:  
 ● Above Surface  
 ○ Below Surface  
 131.8 137.9  
 X1 = A: Feed Composition  
 X2 = B: Mixing Time  
 Actual Factors  
 C: Fermentation Time = 50  
 D: Baking Temperature = 275



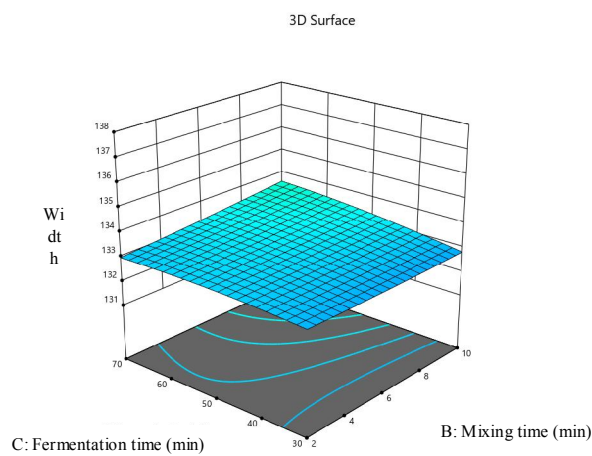
**a**

Factor Coding: Actual  
 Design Points:  
 ● Above Surface  
 ○ Below Surface  
 131.8 137.9  
 Width = 133.2  
 Std = 28 Run # 7  
 X1 = A: Feed Composition = 75  
 X2 = C: Fermentation time = 30  
 Actual Factors  
 B: Mixing Time = 6  
 D: Baking Temperature = 275



**b**

Factor Coding: Actual  
 Design Points:  
 ● Design Points  
 131.8 137.9  
 X1 = B: Mixing Time  
 X2 = C: Fermentation Time  
 Actual Factors  
 A: Feed Composition = 27.5  
 D: Baking temperature = 275



**c**

**Fig. 4.7:** Effect of independent variables on Width (WD) of low-gluten flat breads (a): feed composition and mixing time on WD (b): feed composition and fermentation time on WD (c) : mixing time and fermentation time on WD

#### 4.2.2.1.7 Thickness (THICK)

Thickness of LGFB varied from 6.03 to 9.02 mm (Table 4.6a). The significant predicted model for Thickness is given below in equation

$$\text{THICK} = 8.68 + 1.39A - 1.11A^2 - 0.40B^2 - 0.46C^2 \dots\dots 4.7$$

The fitted regression equation (4.7) and response surface plots (Fig. 4.8) indicated that Thickness increased significantly with the increase in rice flour composition (A). Table 4.13 reveals that out of different independent variables only feed formulation (A) had significant linear effect on THICK, whereas all the independent variables except baking temperature (D) had significant quadratic effect on THICK.

#### 4.2.2.1.8 Spread Ratio (SR)

Spread ratio of LGFB varied from 14.33 to 19.87 (Table 4.6a). The significant predicted model for Spread ratio is given below in equation

$$\text{SR} = 14.45 - 2.60A + 0.05C + 2.73A^2 + 0.75C^2 \dots\dots 4.8$$

The fitted regression equation (4.8) and response surface plots (Fig. 4.9) demonstrates that with the increase in rice flour composition (A) spread ratio decreased significantly whereas, spread ratio increased significantly with the increase in fermentation time (C). Table (4.14) indicates that except mixing time (B) and baking temperature (D) the two independent variables show significant linear effects on spread ratio. whereas all the independent variables except mixing time (B) and baking temperature (D) had significant quadratic effect on SR.

**Table 4.13: Regression coefficient and model statistics for Thickness (THICK)**

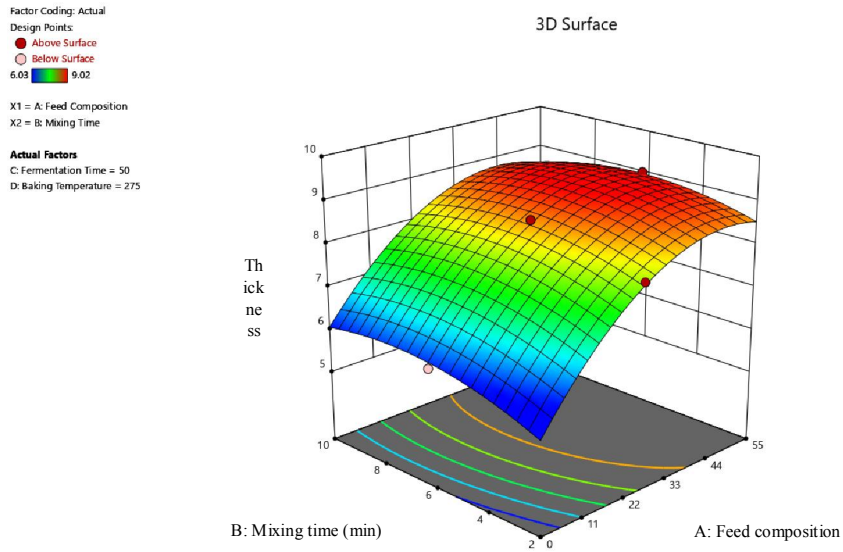
Source	Coefficient Estimate	Sum of Squares	Df	Standard error	F-value	p-value Prob >F
Model	8.68	13.93	14	0.0030	18364.63	< 0.0001***
A-Feed Composition	1.39	11.66	1	0.0032	2.151E+05	< 0.0001***
B-Mixing Time	0.0464	0.0128	1	0.0030	236.36	0.1218
C-Fermentation Time	0.0213	0.0027	1	0.0030	49.94	0.1735
D-Baking Temperature	-0.0416	0.0103	1	0.0030	190.25	0.7449
AB	0.1292	0.0140	1	0.0080	257.84	0.6131
AC	0.0634	0.0034	1	0.0080	62.06	0.4652
AD	0.0250	0.0005	1	0.0080	9.66	0.3125
BC	0.0325	0.0011	1	0.0074	19.49	0.2978
BD	-0.0025	6.181E-06	1	0.0074	0.1141	0.7402
CD	0.0175	0.0003	1	0.0074	5.64	0.2130
A <sup>2</sup>	-1.11	2.55	1	0.0059	46985.45	< 0.0001***
B <sup>2</sup>	-0.401	0.5505	1	0.0057	10158.94	< 0.0001***
C <sup>2</sup>	-0.4630	0.6725	1	0.0057	12410.37	< 0.0001***
D <sup>2</sup>	-0.2500	0.1060	1	0.0057	1956.63	< 0.6154

\*Significant at P<0.05; \*\*Significant at P<0.01; \*\*\*Significant at P<0.001

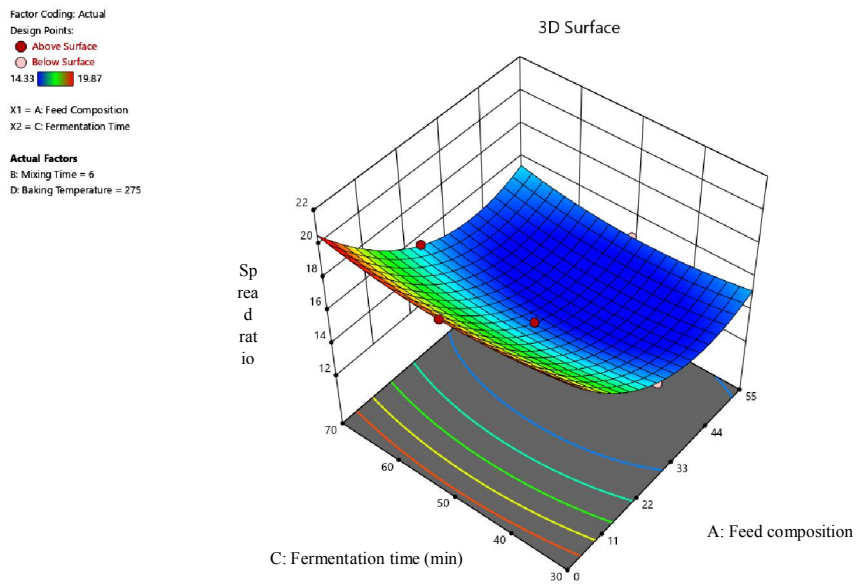
**Table 4.14: Regression coefficient and model statistics for Spread ratio (SR)**

Source	Coefficient Estimate	Sum of Squares	Df	Standard error	F-value	p-value Prob >F
Model	14.45	45.18	14	0.0062	14175.77	< 0.0001***
A-Feed Composition	-2.60	35.96	1	0.0065	1.579E+05	< 0.0001
B-Mixing Time	0.0036	0.0001	1	0.0062	0.3362	0.5706
C-Fermentation Time	0.0591	0.0208	1	0.0062	91.45	< 0.0001**
D-Baking Temperature	0.0044	0.0001	1	0.0062	0.5122	0.4852
AB	0.0062	0.0000	1	0.0165	0.1398	0.7137
AC	0.1184	0.0117	1	0.0165	51.61	0.7001
AD	-0.0851	0.0061	1	0.0165	26.63	0.1297
BC	0.0250	0.0006	1	0.0151	2.75	0.1183
BD	0.0049	0.0000	1	0.0151	0.1046	0.7508
CD	0.0405	0.0016	1	0.0151	7.20	0.5170
A <sup>2</sup>	2.73	11.77	1	0.0120	51686.12	< 0.0001***
B <sup>2</sup>	0.5869	0.5837	1	0.0116	2563.87	0.4210
C <sup>2</sup>	0.7569	0.9708	1	0.0116	4264.40	< 0.0001***
D <sup>2</sup>	0.5864	0.5833	1	0.0116	2562.20	0.2011

\*Significant at P<0.05; \*\*Significant at P<0.01; \*\*\*Significant at P<0.001



**Fig. 4.8:** Effect of feed composition and mixing time on thickness of low-gluten flat breads



**Fig. 4.9:** Effect of feed composition and fermentation time on Spread ratio (SR) of low-gluten flat breads

#### 4.2.2.1.9 Weight (WT)

The weight of LGFB varied from 50.73 to 63.68 g (Table 4.6a). The predicted model obtained from regression analysis for WT was developed as follows.

$$\text{WT} = 55.82 + 6.49A + 1.34A^2 - 0.24B^2 - 0.257C^2 \dots\dots\dots 4.9$$

The fitted regression equation (4.9) and response surface plots (Fig. 4.10) indicated that Weight of bread samples increased significantly with the increase in rice flour composition (A). Table (4.15) reveals that out of different independent variables only feed composition (A) had significant linear effect on weight of bread samples, whereas all the independent variables except baking temperature (D) had significant quadratic effects on weight of bread samples (Table 4.15).

#### 4.2.2.1.10 Volume index (VI)

The volume index of LGFB varied from 1.57 to 1.75cm (Table 4.6b). The predicted model obtained from regression analysis for VI was developed as follows.

$$\text{VI} = 1.67 - 0.09A + 0.01B + 0.016C - 0.007D^2 \dots\dots\dots 4.10$$

The fitted regression equation (4.10) and response surface plots (Fig. 4.11) indicate that with the increase in mixing time (B) and fermentation time (C), volume index was increased. Whereas, with the increase in rice flour composition (A) volume index decreased significantly. The data depicted in (Table 4.16) indicates that all the independent variables except baking temperature (D) had significant linear effects on volume index. The (Table 4.16) also shows negative significant quadratic effect of baking temperature ( $D^2$ ) on volume index of bread samples.

**Table 4.15: Regression coefficient and model statistics for Weight (WT)**

Source	Coefficient Estimate	Sum of Squares	Df	Standard error	F-value	p-value Prob >F
Model	55.82	232.60	14	0.0272	3842.57	< 0.0001***
A-Feed Composition	6.49	224.28	1	0.0285	51870.46	< 0.0001***
B-Mixing Time	0.0147	0.0013	1	0.0269	0.2965	0.5941
C-Fermentation Time	0.0040	0.0001	1	0.0269	0.0215	0.8853
D-Baking Temperature	-0.0305	0.0055	1	0.0270	1.28	0.2754
AB	-0.1430	0.0171	1	0.0719	3.96	0.0652
AC	-0.1205	0.0122	1	0.0719	2.81	0.1143
AD	-0.1152	0.0111	1	0.0718	2.57	0.1297
BC	0.1375	0.0189	1	0.0658	4.37	0.0740
BD	0.1130	0.0128	1	0.0657	2.95	0.1062
CD	0.1329	0.0177	1	0.0657	4.09	0.0614
A <sup>2</sup>	1.34	2.86	1	0.0523	661.31	< 0.0001***
B <sup>2</sup>	-0.2422	0.0994	1	0.0505	22.99	0.0002***
C <sup>2</sup>	-0.2572	0.1121	1	0.0505	25.92	0.0001***
D <sup>2</sup>	-0.0989	0.0166	1	0.0505	3.84	0.0690

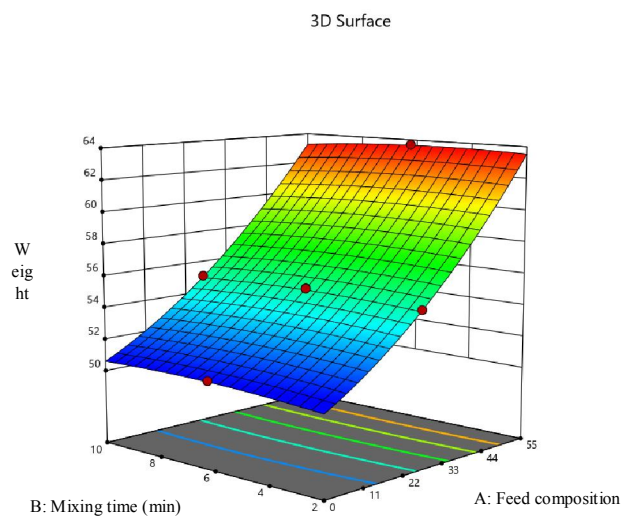
\*Significant at P<0.05; \*\*Significant at P<0.01; \*\*\*Significant at P<0.001

**Table 4.16: Regression coefficient and model statistics for Volume index (VI)**

Source	Coefficient Estimate	Sum of Squares	Df	Standard error	F-value	p-value Prob >F
Model	1.67	0.0546	14	0.0036	50.97	< 0.0001***
A-Feed Composition	-0.0975	0.0507	1	0.0038	662.92	< 0.0001***
B-Mixing Time	0.0101	0.0006	1	0.0036	7.99	0.0127*
C-Fermentation Time	0.0166	0.0017	1	0.0036	21.57	0.0003***
D-Baking Temperature	-0.0071	0.0003	1	0.0036	3.91	0.0668
AB	0.0043	0.0000	1	0.0096	0.2065	0.6561
AC	0.0036	0.0000	1	0.0096	0.1411	0.7124
AD	-0.0012	1.200E-06	1	0.0096	0.0157	0.9020
BC	0.0050	0.0000	1	0.0087	0.3268	0.5760
BD	0.0002	4.430E-08	1	0.0087	0.0006	0.9811
CD	-0.0097	0.0001	1	0.0087	1.22	0.2870
A <sup>2</sup>	-0.0075	0.0001	1	0.0070	1.15	0.3009
B <sup>2</sup>	-0.0016	4.491E-06	1	0.0067	0.0587	0.8118
C <sup>2</sup>	-0.0016	4.491E-06	1	0.0067	0.0587	0.8118
D <sup>2</sup>	-0.0763	0.0005	1	0.0067	5.93	0.0279*

\*Significant at P<0.05; \*\*Significant at P<0.01; \*\*\*Significant at P<0.001

Factor Coding: Actual  
Design Points  
● Above Surface  
○ Below Surface  
50.75 63.68  
X1 = A: Feed Composition  
X2 = B: Mixing Time  
Actual Factors  
C: Fermentation Time = 50  
D: Baking Temperature = 275

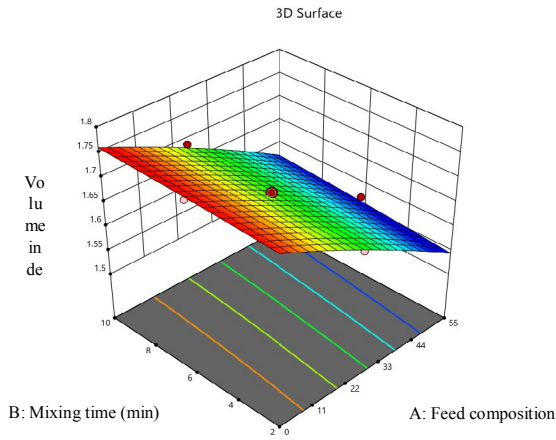


**Fig. 4.10:** Effect of feed composition and mixing time Weight of low-gluten flat breads

Factor Coding: Actual  
 Design Points:  
 ● Above Surface  
 ○ Below Surface  
 1.57 1.75

Volume Index = 1.68  
 Std # 15 Run # 14  
 X1 = A: Feed Composition = 25  
 X2 = B: Mixing Time = 6

**Actual Factors**  
 C: Fermentation Time = 50  
 D: Baking Temperature = 275

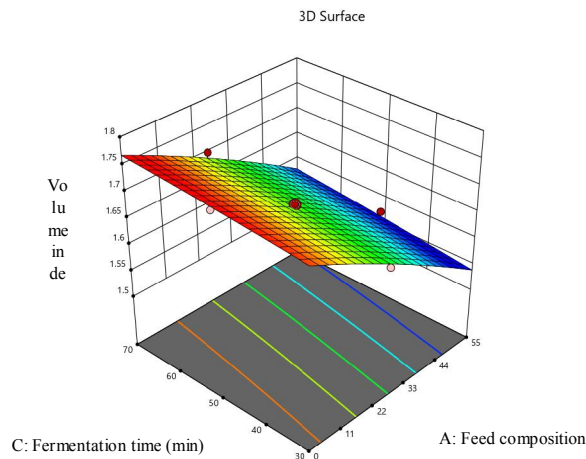


**a**

Factor Coding: Actual  
 Design Points:  
 ● Above Surface  
 ○ Below Surface  
 1.57 1.75

Volume Index = 1.68  
 Std # 13 Run # 30  
 X1 = A: Feed Composition = 25  
 X2 = C: Fermentation Time = 30

**Actual Factors**  
 B: Mixing Time = 6  
 D: Baking Temperature = 275

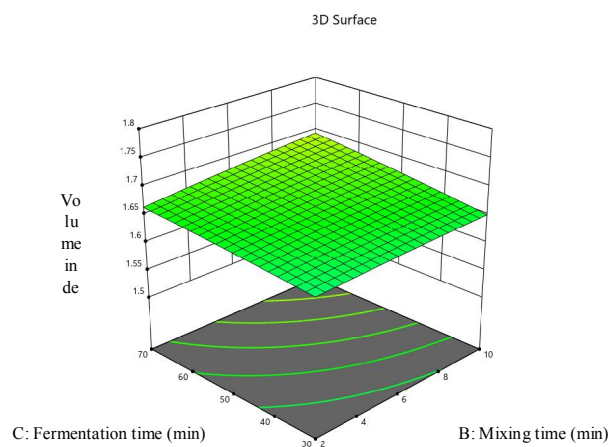


**b**

Factor Coding: Actual  
 Design Points:  
 ● Design Points  
 1.57 1.75

X1 = B: Mixing Time  
 X2 = C: Fermentation Time

**Actual Factors**  
 A: Feed Composition = 275  
 D: Baking Temperature = 275



**c**

**Fig. 4.11:** Effect of independent variables on Volume index (VI) of low-gluten flat breads (a): feed composition and mixing time on VI (b): feed composition and fermentation time on VI (c) : mixing time and fermentation time on VI.

#### 4.2.2.1.11 Specific volume (SV)

The specific volume of LGFB varied from 3.8 to 5.79 (cm<sup>3</sup>/g) (Table 4.6b). The predicted model obtained from regression analysis for SV was developed as follows.

$$SV=4.77- 1.03A \dots\dots 4.11$$

The regression equation (4.11) and response surface plots (Fig.4.12) illustrated that with the increase in rice flour composition (A) specific volume decreased significantly. (Table 4.17) demonstrated out of different independent variables only flour composition (A) exhibited negative significant linear effect on specific volume of bread samples (Table 4.17).

#### 4.2.2.1.12 Puffiness (PUFF)

The Puffiness of low-gluten flat breads varied from 24.33 to 53.10 (%) (Table 4.6b). The predicted model obtained from regression analysis for SV was developed as follows.

$$PUFF= 44.45 - 12.23A - 4.37A^2 \dots\dots 4.11$$

The fitted regression equation (4.11) and response surface plots (Fig. 4.13) indicated that with increase in rice flour composition (A) puffiness decreased significantly. (Table 4.18) indicates that out of different independent variables, only flour composition (A) showed negative significant linear effect on puffiness. Further more puffiness of bread samples were significantly affected by the quadratic effect of flour composition (A)<sup>2</sup> (Table 4.18)

**Table 4.17: Regression coefficient and model statistics for Specific volume (SV)**

Source	Coefficient Estimate	Sum of Squares	Df	Standard error	F-value	p-value Prob >F
Model	4.77	5.73	14	0.0090	862.91	< 0.0001***
A-Feed Composition	-1.03	5.68	1	0.0094	11981.68	< 0.0001***
B-Mixing Time	0.0158	0.0015	1	0.0089	3.13	0.0971
C-Fermentation Time	0.0156	0.0014	1	0.0089	3.06	0.1008
D-Baking Temperature	0.0100	0.0006	1	0.0089	1.25	0.2813
AB	0.0018	2.677E-06	1	0.0238	0.0056	0.9411
AC	-0.0155	0.0002	1	0.0238	0.4248	0.5244
AD	0.0389	0.0013	1	0.0238	2.67	0.1228
BC	-0.0075	0.0001	1	0.0218	0.1187	0.7353
BD	-0.0073	0.0001	1	0.0218	0.1132	0.7411
CD	0.0178	0.0003	1	0.0218	0.6702	0.4258
A <sup>2</sup>	0.0254	0.0010	1	0.0173	2.15	0.1631
B <sup>2</sup>	-0.0147	0.0004	1	0.0167	0.7742	0.3928
C <sup>2</sup>	-0.0297	0.0015	1	0.0167	3.16	0.0959
D <sup>2</sup>	-0.0190	0.0006	1	0.0167	1.29	0.2744

\*Significant at P<0.05; \*\*Significant at P<0.01; \*\*\*Significant at P<0.001

**Table 4.18: Regression coefficient and model statistics for Puffiness (P)**

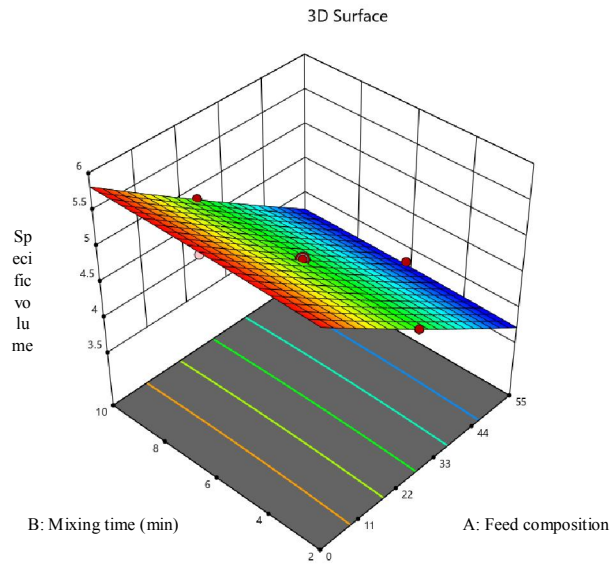
Source	Coefficient Estimate	Sum of Squares	Df	Standard error	F-value	p-value Prob >F
Model	44.45	869.23	14	0.7376	19.46	< 0.0001***
A-Feed Composition	-12.23	797.33	1	0.7736	249.95	< 0.0001***
B-Mixing Time	0.0871	0.0452	1	0.7319	0.0142	0.9068
C-Fermentation Time	0.1878	0.2100	1	0.7319	0.0658	0.8010
D-Baking Temperature	0.4329	1.11	1	0.7326	0.3491	0.5634
AB	0.0889	0.0066	1	1.95	0.0021	0.9643
AC	0.1322	0.0146	1	1.95	0.0046	0.9469
AD	-0.0705	0.0042	1	1.95	0.0013	0.9716
BC	0.1100	0.0121	1	1.79	0.0038	0.9517
BD	-0.0422	0.0018	1	1.79	0.0006	0.9815
CD	-0.0900	0.0081	1	1.79	0.0025	0.0077**
A <sup>2</sup>	-4.37	30.21	1	1.42	9.47	0.1011
B <sup>2</sup>	-2.40	9.73	1	1.37	3.05	0.1011
C <sup>2</sup>	-2.45	10.14	1	1.37	3.18	0.0948
D <sup>2</sup>	-1.42	3.42	1	1.37	1.07	0.3172

\*Significant at P<0.05; \*\*Significant at P<0.01; \*\*\*Significant at P<0.001

Factor Coding: Actual  
 Design Points:  
 ● Above Surface  
 ○ Below Surface  
 3.8 5.79

Specific Volume = 4.87  
 Std # 10 Run # 26  
 X1 = A: Feed Composition = 25  
 X2 = B: Mixing Time = 6

Actual Factors  
 C: Fermentation Time = 50  
 D: Baking Temperature = 275

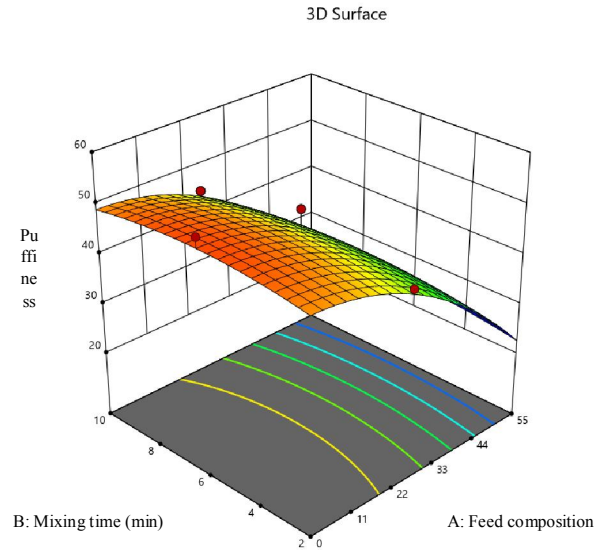


**Fig. 4.12:** Effect of feed composition and mixing time specific volume of low-gluten flat breads

Factor Coding: Actual  
 Design Points:  
 ● Above Surface  
 ○ Below Surface  
 24.33 53.1

X1 = A: Feed Composition  
 X2 = B: Mixing Time

Actual Factors  
 C: Fermentation Time = 50  
 D: Baking Temperature = 275



**Fig. 4.13:** Effect of feed composition and mixing time puffiness of low-gluten flat breads

#### 4.2.2.1.13 Oven Spring (OS)

The oven spring of low-gluten flat breads varied from 1.51 to 1.73 (cm) (Table 4.6b). The predicted model obtained from regression analysis for OS was developed as follows.

$$\text{OS} = 1.62 - 0.11A + 0.01B + 0.02C + 0.015BC \dots\dots 4.12$$

The fitted regression equation (4.12) and response surface plots (Fig. 4.14) demonstrates that with the increase in mixing time (B) and fermentation time (C) oven spring increased significantly. whereas, with the increase in rice flour composition (A) the oven spring of bread samples decreased significantly. (Table 4.19) shows that except baking temperature (D) all the three independent variables show significant linear effects on oven spring of bread. Also oven spring of bread samples were significantly affected by the interactive effect of mixing time and fermentation time (BC) and fermentation time and baking temperature (CD). (Table 4.19).

**Table 4.19: Regression coefficient and model statistics for Oven spring (OS)**

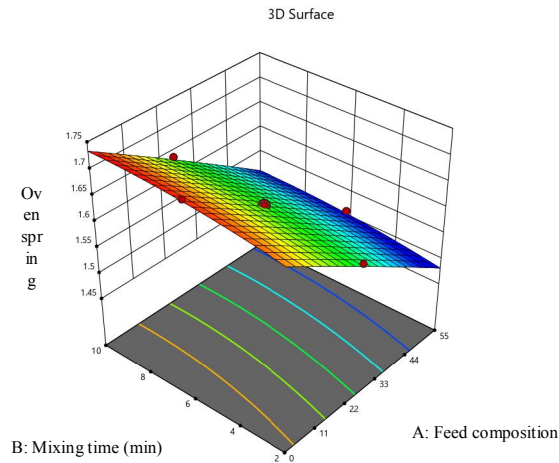
Source	Coefficient Estimate	Sum of Squares	Df	Standard error	F-value	p-value Prob >F
Model	1.62	0.0718	14	0.0024	148.18	< 0.0001***
A-Feed Composition	-0.1106	0.0652	1	0.0025	1882.59	< 0.0001
B-Mixing Time	0.0150	0.0013	1	0.0024	38.70	< 0.0001***
C-Fermentation Time	0.0235	0.0033	1	0.0024	94.94	< 0.0001***
D-Baking Temperature	0.0067	0.0003	1	0.0024	7.71	0.0141
AB	0.0000	0.0000	1	0.0064	0.0000	1.0000
AC	-0.0057	0.0000	1	0.0064	0.7906	0.3879
AD	-0.0008	4.778E-07	1	0.0064	0.0138	0.9080
BC	0.0150	0.0002	1	0.0059	6.50	0.0222*
BD	0.0000	0.0000	1	0.0059	0.0000	1.0000
CD	0.0250	0.0006	1	0.0059	18.12	0.0708
A <sup>2</sup>	-0.0020	6.483E-06	1	0.0047	0.1873	0.6714
B <sup>2</sup>	-0.0081	0.0001	1	0.0045	3.20	0.0937
C <sup>2</sup>	-0.0081	0.0001	1	0.0045	3.20	0.0937
D <sup>2</sup>	-0.0030	0.0000	1	0.0045	0.4271	0.5233

\*Significant at P<0.05; \*\*Significant at P<0.01; \*\*\*Significant at P<0.001

Factor Coding: Actual  
 Design Points:  
 ● Above Surface  
 ○ Below Surface  
 1.51 1.73

Oven Spring = 1.63  
 Std # 10 Run # 26  
 X1 = A: Feed Composition = 25  
 X2 = B: Mixing Time = 6

**Actual Factors**  
 C: Fermentation Time = 50  
 D: Baking Temperature = 275

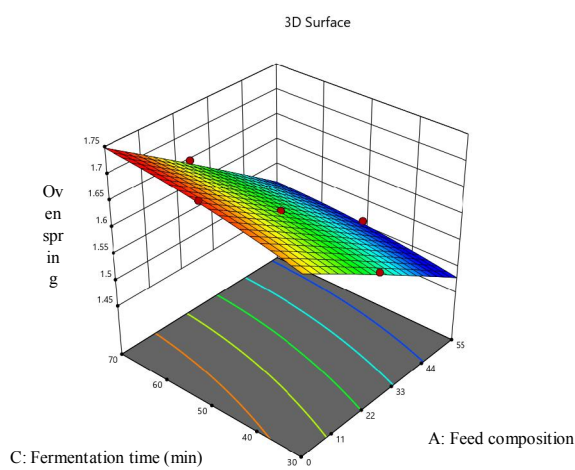


**a**

Factor Coding: Actual  
 Design Points:  
 ● Above Surface  
 ○ Below Surface  
 1.51 1.73

X1 = A: Feed Composition  
 X2 = C: Fermentation Time

**Actual Factors**  
 B: Mixing Time = 6  
 D: Baking Temperature = 275

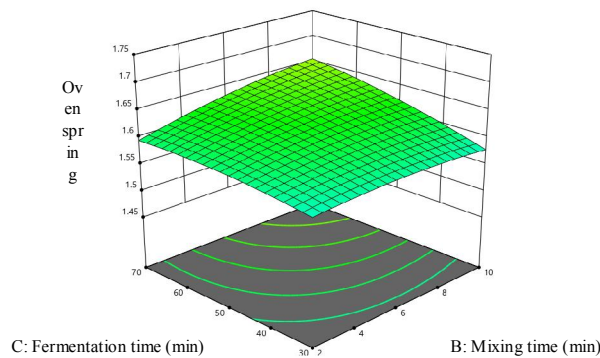


**b**

Factor Coding: Actual  
 Design Points:  
 ● Design Points  
 1.51 1.73

X1 = B: Mixing Time  
 X2 = C: Fermentation Time

**Actual Factors**  
 A: Feed Composition = 27.5  
 D: Baking Temperature = 275



**c**

**Fig. 4.14:** Effect of independent variables on oven spring (OS) of low-gluten flat breads (a): feed composition and mixing time on OS (b): feed composition and fermentation time on OS (c): mixing time and fermentation time on OS

Luminosity ( $L^*$  value) of low-gluten flat breads (LGFB) varied from 40.34 to 51.37 (Table 4.6b) while redness ( $a^*$ ) and yellowness ( $b^*$ ) ranged from 1.99 to 4.82 and 24.11 to 33.85, respectively. The models generated for luminosity ( $L^*$ ), redness ( $a^*$ ), yellowness ( $b^*$ ), are given below in equations:

$$L^* = 46.04 + 5.48A + 0.35B - 0.10D - 0.187A^2 + 0.12B^2 \dots\dots 4.14$$

$$a^* = 3.29 - 1.80A - 0.42B \dots\dots 4.15$$

$$b^* = 29.39 - 5.25A \dots\dots\dots 4.16$$

The fitted regression equation (4.14) for  $L^*$  and response surface plots (Fig. 4.15) indicates that with the increase in flour composition (A) and mixing time (B) the  $L^*$  value increased significantly, whereas with the increase in baking temperature (D), the  $L^*$  value decreased significantly. The regression equations (4.15 and 4.16) and response surface plots (Fig.4.16 and Fig 4.17) shows that with the increase in rice flour composition (A) in feed composition,  $a^*$  and  $b^*$  values were found to decrease significantly. (Table 4.20) shows that except fermentation time (C) all other independent variables had significant linear effects on  $L^*$  value, whereas out of different independent variables only flour composition ( $A^2$ ) and mixing time ( $B^2$ ) had significant quadratic effects on  $L^*$  value. Table 4.21 that out of different independent variables only the significant linear on  $a^*$  value were shown by feed Composition (A) and mixing time (B). likewise Table 4.22 shows that out of different independent variables only feed Composition (A) had significant linear effect on  $b^*$  value.

**Table 4.20: Regression coefficient and model statistics for Lightness ( $L^*$ )**

Source	Coefficient Estimate	Sum of Squares	Df	Standard error	F-value	p-value Prob >F
Model	46.04	161.66	14	0.0192	5329.37	< 0.0001***
A-Feed Composition	5.48	159.84	1	0.0202	73767.26	< 0.0001
B-Mixing Time	0.3561	0.7552	1	0.0191	348.52	< 0.0001***
C-Fermentation Time	0.1724	0.1771	1	0.0191	81.72	0.8501
D-Baking Temperature	-0.1051	0.0657	1	0.0191	30.32	< 0.0001***
AB	0.0137	0.0002	1	0.0509	0.0728	0.7910
AC	0.0658	0.0036	1	0.0509	1.67	0.2156
AD	0.0325	0.0009	1	0.0509	0.4095	0.5319
BC	-0.0175	0.0003	1	0.0465	0.1413	0.7122
BD	-0.0095	0.0001	1	0.0465	0.0416	0.8411
CD	-0.0290	0.0008	1	0.0465	0.3872	0.5431
A <sup>2</sup>	-0.1877	0.0557	1	0.0370	25.71	0.0001***
B <sup>2</sup>	0.1213	0.0249	1	0.0358	11.50	0.0040**
C <sup>2</sup>	-0.0037	0.0000	1	0.0358	0.0109	0.9184
D <sup>2</sup>	0.0502	0.0043	1	0.0357	1.97	0.1805

\*Significant at P<0.05; \*\*Significant at P<0.01; \*\*\*Significant at P<0.001

**Table 4.21: Regression coefficient and model statistics for redness ( $a^*$ ) value**

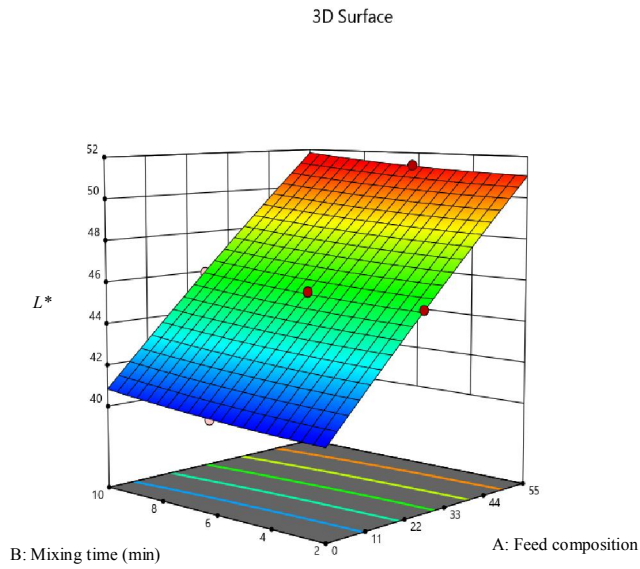
Source	Coefficient Estimate	Sum of Squares	Df	Standard error	F-value	p-value Prob >F
Model	3.29	21.45	14	0.0520	96.67	< 0.0001***
A-Feed Composition	-1.80	20.56	1	0.0545	1296.80	< 0.0001
B-Mixing Time	-0.4273	0.3942	1	0.0516	24.87	0.0002***
C-Fermentation Time	-0.0764	0.0348	1	0.0516	2.19	0.1594
D-Baking Temperature	0.0889	0.0469	1	0.0516	2.96	0.1059
AB	-0.1024	0.0088	1	0.1376	0.5541	0.4682
AC	-0.0742	0.0046	1	0.1376	0.2906	0.5977
AD	0.0219	0.0004	1	0.1375	0.0254	0.8756
BC	-0.0075	0.0001	1	0.1259	0.0035	0.9533
BD	-0.0034	0.0000	1	0.1259	0.0007	0.9789
CD	0.0015	2.210E-06	1	0.1259	0.0001	0.9907
A <sup>2</sup>	-0.1201	0.0228	1	0.1001	1.44	0.2491
B <sup>2</sup>	0.1701	0.0490	1	0.0967	3.09	0.0990
C <sup>2</sup>	0.3201	0.1737	1	0.0967	10.95	0.0848
D <sup>2</sup>	0.0773	0.0101	1	0.0967	0.6387	0.4366

\*Significant at P<0.05; \*\*Significant at P<0.01; \*\*\*Significant at P<0.001

Factor Coding: Actual  
 Design Points:  
 ● Above Surface  
 ○ Below Surface  
 40.34 51.37

X1 = A: Feed Composition  
 X2 = B: Mixing Time

**Actual Factors**  
 C: Fermentation Time = 50  
 D: Baking Temperature = 275

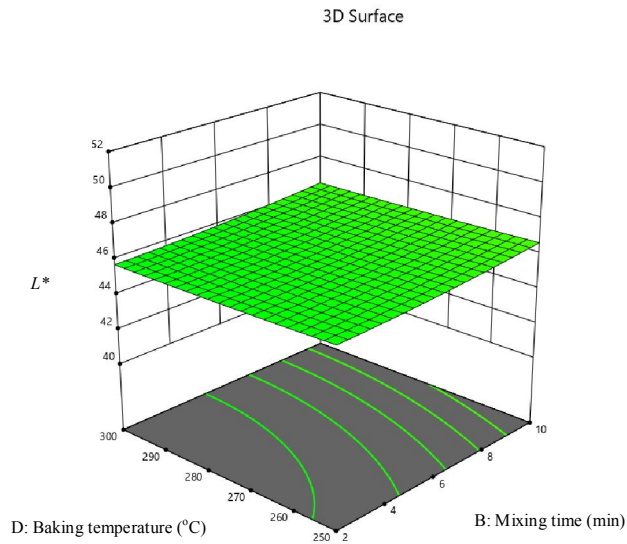


**a**

Factor Coding: Actual  
 Design Points:  
 ● Design Points  
 40.34 51.37

X1 = B: Mixing Time  
 X2 = D: Baking Temperature

**Actual Factors**  
 A: Feed Composition = 27.5  
 C: Fermentation Time = 50



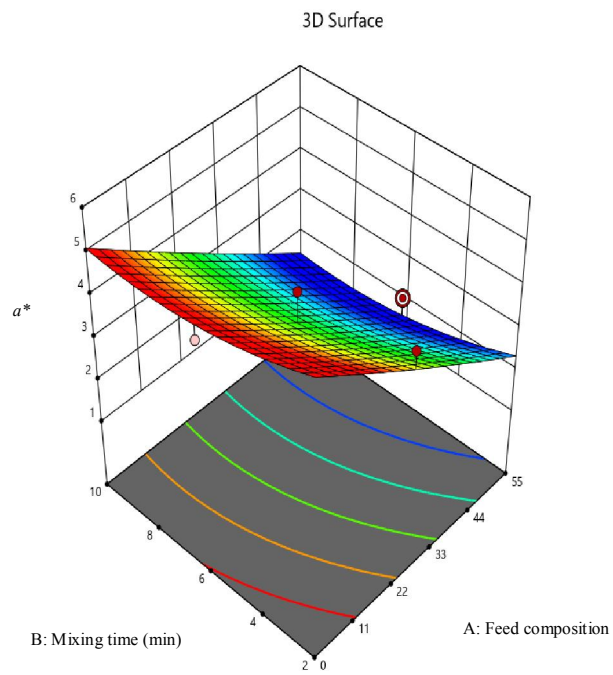
**b**

**Fig. 4.15:** Effect of independent variables on luminosity ( $L^*$ ) of low-gluten flat breads (a): feed composition and mixing time on  $L^*$  (b): mixing time and baking temperature time on  $L^*$

Factor Coding: Actual  
Design Points:  
● Above Surface  
○ Below Surface  
1.99 4.82

$a^* = 1.99$   
Std # 20 Run # 8  
X1 = A: Feed Composition = 55  
X2 = B: Mixing Time = 6

**Actual Factors**  
C: Fermentation Time = 50  
D: Baking Temperature = 275



**Fig. 4.16:** Effect of feed composition and mixing time on redness ( $a^*$ ) of low-gluten flat breads

**Table 4.22: Regression coefficient and model statistics for Yellowness (b\*)**

Source	Coefficient Estimate	Sum of Squares	Df	Standard error	F-value	p-value Prob >F
Model	29.39	133.54	14	0.2934	18.90	< 0.0001***
A-Feed Composition	-5.25	132.59	1	0.3077	262.77	< 0.0001***
B-Mixing Time	-0.2277	0.3087	1	0.2911	0.6119	0.4463
C-Fermentation Time	-0.1265	0.0953	1	0.2911	0.1888	0.6701
D-Baking Temperature	0.1149	0.0785	1	0.2914	0.1556	0.6988
AB	-0.1516	0.0192	1	0.7762	0.0381	0.8478
AC	-0.0618	0.0032	1	0.7762	0.0063	0.9376
AD	0.0218	0.0004	1	0.7760	0.0008	0.9779
BC	-0.0150	0.0002	1	0.7103	0.0004	0.9834
BD	0.0166	0.0003	1	0.7102	0.0005	0.9817
CD	0.0282	0.0008	1	0.7102	0.0016	0.9688
A <sup>2</sup>	0.5177	0.4237	1	0.5650	0.8397	0.3740
B <sup>2</sup>	0.5307	0.4773	1	0.5457	0.9458	0.3462
C <sup>2</sup>	0.4907	0.4080	1	0.5457	0.8086	0.3827
D <sup>2</sup>	0.2137	0.0775	1	0.5454	0.1535	0.7007

\*Significant at P<0.05; \*\*Significant at P<0.01; \*\*\*Significant at P<0.001

#### 4.2.2.1.15 Overall Acceptability (OA)

The overall acceptability score (OA) of the developed LGFB ranged from 3.3 to 4.23. The predicted model can be described by the following equation in terms of coded levels as shown (Table 4.23)

$$\mathbf{O.A = 3.71 + 0.414A + 0.005C \dots 4.17}$$

The fitted regression equation (4.17) and response surface plots (Fig. 4.18) shows that with the increase in feed composition (A) and fermentation time (C) the overall acceptability of bread was increased significantly. (Table 4.23) indicates that except mixing time (B) and baking temperature (D) the other two independent variables had significant linear effects on OA (Table 4.23).

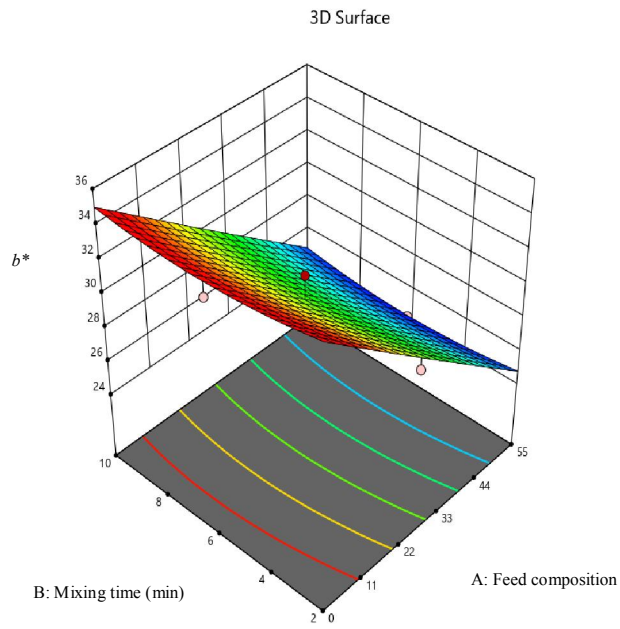
#### 4.2.2.1.16 Yield (Y)

The yield of low-gluten flat breads varied from 129.49 to 140.58 (%) (Table 4.6b). The predicted model obtained from regression analysis for Y was developed as follows.

Factor Coding: Actual  
 Design Points  
 ● Above Surface  
 ○ Below Surface  
 24.11 93.85

$b^* = 29.47$   
 Std # 15 Run # 14  
 X1 = A: Feed Composition = 25  
 X2 = B: Mixing Time = 6

**Actual Factors**  
 C: Fermentation Time = 50  
 D: Baking Temperature = 275



**Fig. 4.17:** Effect of feed composition and mixing time on yellowness ( $b^*$ ) of low-gluten flat breads

$$Y=134.90+ 5.57A+0.06B+ 0.09C - 0.091D+ 0.11AB+ 0.08AC+0.07BD+0.12A^2 -0.09C^2 \dots 4.13$$

The fitted regression equation (4.13) and response surface plots (Fig. 4.19) demonstrate that with increase in rice flour composition (A), mixing time (B) and fermentation time (C), the yield (%) was increased significantly., while with the increase in baking temperature(D) the yield (%) decreased significantly.(Table 4.24) illustrates that all independent variables exhibited significant linear effects on yield of bread samples. Further more out of different interactions the interactive effects of of flour composition and mixing time (AB); flour composition and fermentation time (AC) and mixing time and baking temperature (BD) were also found to be significant on yield (%) of breads. Also the quadratic effects of feed composition (A<sup>2</sup>) and fermentation time (C)<sup>2</sup> were found to have significant effect on bread yield. (Table 4.24)

**Table 4.23: Regression coefficient and model statistics for overall acceptability (OAA)**

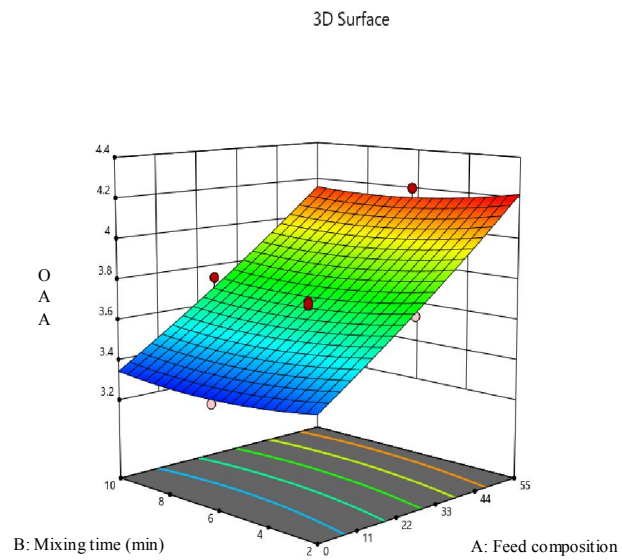
Source	Coefficient Estimate	Sum of Squares	Df	Standard error	F-value	p-value Prob >F
<b>Model</b>	3.71	0.9407	14	0.0127	70.88	< 0.0001***
A-Feed Composition	0.4144	0.9154	1	0.0133	965.55	< 0.0001***
B-Mixing Time	-0.0235	0.0033	1	0.0126	3.48	0.0818
C-Fermentation Time	-0.0101	0.0006	1	0.0126	0.6434	0.4350
D-Baking Temperature	0.0183	0.0020	1	0.0126	2.11	0.1674
AB	-0.0072	0.0000	1	0.0336	0.0462	0.8327
AC	-0.0043	0.0000	1	0.0336	0.0166	0.8991
AD	-0.0022	3.876E-06	1	0.0336	0.0041	0.9499
BC	0.0000	0.0000	1	0.0308	0.0000	1.0000
BD	0.0013	1.730E-06	1	0.0308	0.0018	0.9665
CD	0.0008	6.229E-07	1	0.0308	0.0007	0.9799
A <sup>2</sup>	0.0248	0.0010	1	0.0245	1.03	0.3267
B <sup>2</sup>	0.0388	0.0025	1	0.0237	2.69	0.1220
C <sup>2</sup>	0.0488	0.0040	1	0.0237	4.25	0.0670
D <sup>2</sup>	-0.0155	0.0004	1	0.0236	0.4323	0.5208

\*Significant at P<0.05; \*\*Significant at P<0.01; \*\*\*Significant at P<0.001

Factor Coding: Actual  
 Design Points:  
 ● Above Surface  
 ○ Below Surface  
 3.3 4.2

X1 = A: Feed Composition  
 X2 = B: Mixing Time

**Actual Factors**  
 C: Fermentation Time = 50  
 D: Baking Temperature = 275



**Fig. 4.18:** Effect of feed composition and mixing time on overall acceptability of low-gluten flat breads

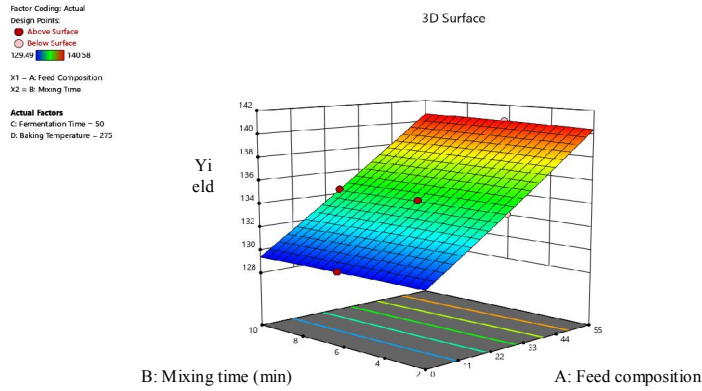
**Table 4.24: Regression coefficient and model statistics for Yield (Y)**

Source	Coefficient Estimate	Sum of Squares	Df	Standard error	F-value	p-value Prob >F
Model	134.90	166.67	14	0.0139	10464.77	< 0.0001
A-Feed Composition	5.57	165.10	1	0.0146	1.451E+05	< 0.0001
B-Mixing Time	0.0636	0.0241	1	0.0138	21.18	0.0003
C-Fermentation Time	0.0989	0.0582	1	0.0138	51.16	< 0.0001
D-Baking Temperature	-0.0911	0.0494	1	0.0138	43.39	< 0.0001
AB	0.1146	0.0110	1	0.0369	9.66	0.0072
AC	0.0812	0.0055	1	0.0369	4.85	0.0437
AD	-0.0720	0.0043	1	0.0368	3.82	0.0696
BC	0.0175	0.0003	1	0.0337	0.2692	0.6114
BD	0.0732	0.0054	1	0.0337	4.71	0.0465
CD	0.0432	0.0019	1	0.0337	1.64	0.2192
A <sup>2</sup>	0.1299	0.0267	1	0.0268	23.44	0.0002
B <sup>2</sup>	-0.0325	0.0018	1	0.0259	1.58	0.2285
C <sup>2</sup>	-0.0925	0.0145	1	0.0259	12.75	0.0028
D <sup>2</sup>	-0.0031	0.0000	1	0.0259	0.0146	0.9055

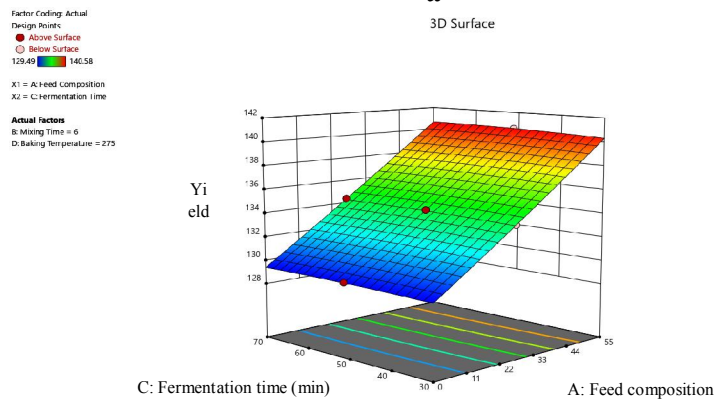
\*Significant at P<0.05; \*\*Significant at P<0.01; \*\*\*Significant at P<0.001

#### 4.2.2.2 Optimization

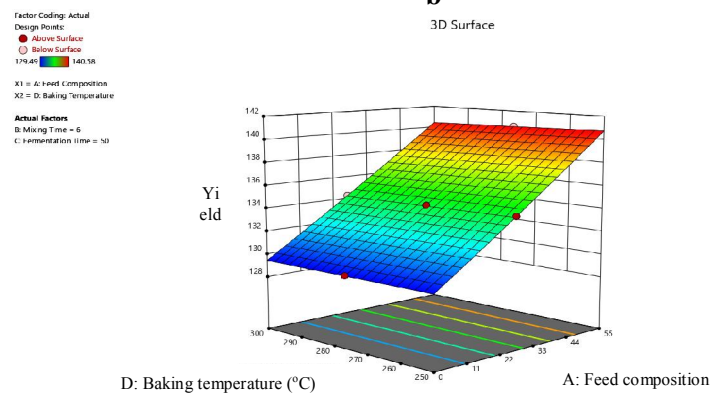
The optimum processing conditions for development of low-gluten flat bread (LGFB) was obtained on the basis of applying desirability function method and the desirability value obtained was 0.90 (Fig. 4.20). The optimum predicted conditions for development of low-gluten flat bread were feed proportion (wheat flour to rice flour 48:52); mixing time (3.3min); fermentation time; (70min) and baking temperature (282°C).The corresponding predicted values for H, SPR, COH, GUM, CHEW, WD, TH, SR,WT,VI, SV, PUFF, OS,  $L^*$ ,  $a^*$ ,  $b^*$ , O.A and Yield were 8.32N, 0.86mm, 0.73, 5.57N, 5.03N, 130.83mm, 8.70mm, 15.29, 61.55g, 1.58cm, 3.97 cm<sup>3</sup>/g, 24.33%, 1.55cm, 50.12\*, 4.06\*, 26.60\* and 4.1 139.93%, respectively. By applying the optimal conditions, the flat breads with H of 8.20N, SPR of 0.85mm, COH of 0.71, G of 5.48N, C of 4.97N, W of 127.25mm, TH of 8.55mm, SRof 15.01, WT of 62.03g,VI of 1.57cm,S.V of 3.95 cm<sup>3</sup>/g, PUFF of 23.85%,  $L^*$  of 48.95,  $a^*$  of 3.91,  $b^*$  of 25.60 , OAA of 4.01 and



**a**



**b**



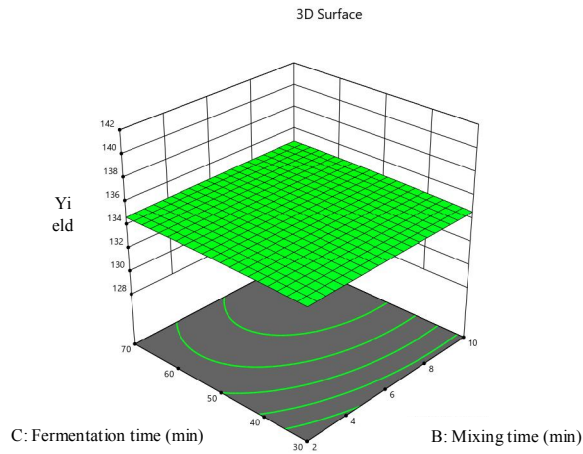
**c**

**Fig. 4.19:** Effect of independent variables on Yield (Y) of low-gluten flat breads (a): feed composition and mixing time on Y (b): feed composition and fermentation time on Y (c) : feed composition and baking temperature (d):mixing time and fermentation time (e):mixing time and baking temperature (f):fermentation time and baking temperature

Contd....

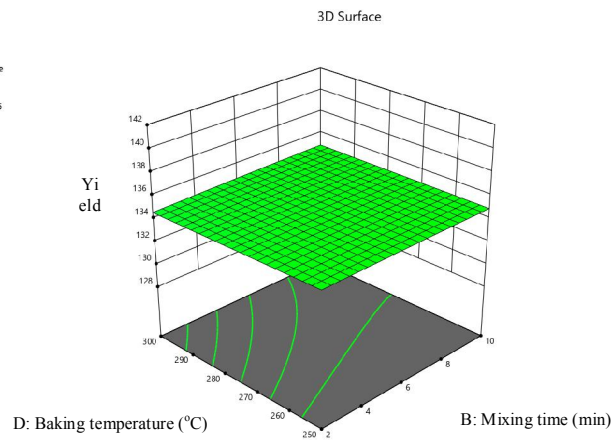
Fig. 4.19” contd....

Factor Coding: Actual  
● Design Points  
129.49 140.58  
X1 = B: Mixing Time  
X2 = C: Fermentation Time  
**Actual Factors**  
A: Feed Composition = 27.5  
D: Baking temperature = 275



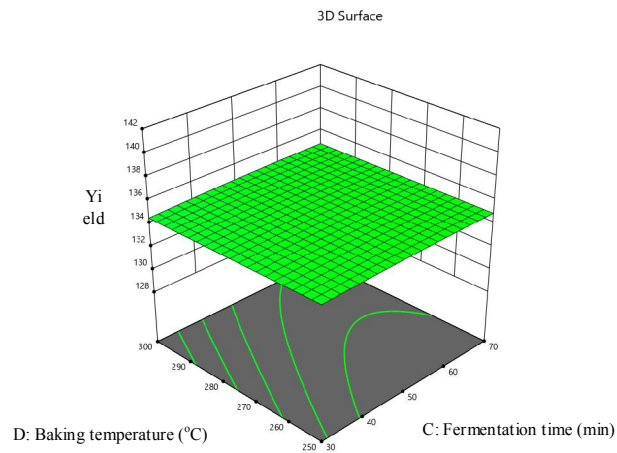
d

Factor Coding: Actual  
● Design Points  
129.49 140.58  
X1 = B: Mixing Time  
X2 = D: Baking Temperature  
**Actual Factors**  
A: Feed Composition = 27.5  
C: Fermentation Time = 50



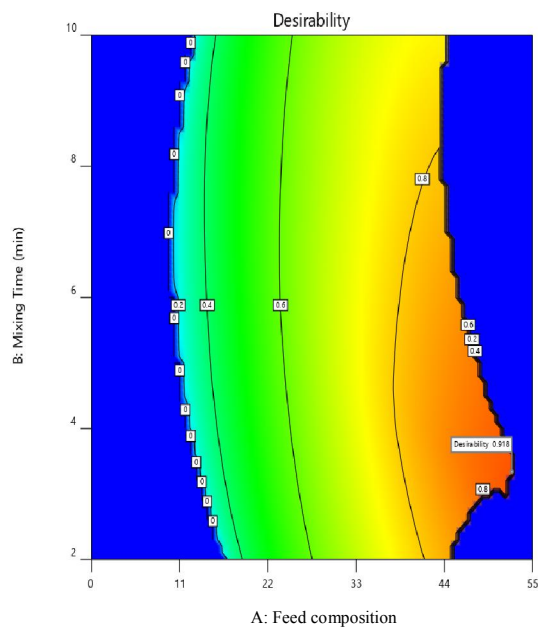
e

Factor Coding: Actual  
● Design Points  
129.49 140.58  
X1 = C: Fermentation Time  
X2 = D: Baking Temperature  
**Actual Factors**  
A: Feed Composition = 27.5  
B: Mixing time = 6



f

Factor Coding: Actual  
0.000 1.000  
X1 = A: Feed Composition  
X2 = B: Mixing Time  
**Actual Factors**  
C: Fermentation Time = 70  
D: Baking Temperature = 282.056



**Fig. 4.20: Desirability response surface plot of low-gluten flat breads**

Yield of 135.53%, were found close to the predicted values with a variation of less than 3% (Table 4.25). The results therefore confirmed the validity and adequacy of the models for predicting dependent variables of the low - gluten flatbread.

**Table 4.25: Predicted responses vs. actual response levels**

Parameters	Predicted values	Actual values	Variation (%)
Hardness (N)	8.32	8.20	1.44
Springness (mm)	0.86	0.85	1.16
Cohesiveness	0.73	0.71	2.7
Gumminess (N)	5.57	5.48	1.61
Chewiness (N)	5.03	4.97	1.19
Width (mm)	130.83	128.25	1.97
Thickness (mm)	8.76	8.55	2.39
Sp.Ratio	15.29	15.01	1.83
Weight (g)	61.55	62.03	0.77
Vol.Index(cm)	1.58	1.54	2.5
Sp.volume (cm <sup>3</sup> /g)	3.97	3.95	0.50
Puffiness (%)	24.33	23.85	1.97
Ov.Spring (cm)	1.53	1.52	1.32
Yield (%)	139.93	135.53	3.14
L*	50.12	48.95	2.33
a*	4.06	3.91	3.69
b*	26.60	25.60	3.75
OAA	4.11	4.01	2.43
Desirability	0.90		

#### 4.2.3 Farinographic studies of optimized blend

The Farinographic studies of optimized rice and wheat blend is given in Table 4.26. The arrival time (3.50±0.01), water absorption capacity (65.4±1.31), and dough development time (5.51±0.09) were significantly (p<0.01) increased

whereas, degree of softening ( $30.00 \pm 1.15$ ), dough stability values ( $2.13 \pm 0.05$ ) and mixing tolerance index ( $52.84 \pm 1.18$ ) were significantly ( $p < 0.01$ ) decreased with rice flour incorporation.

**Table 4.26: Farinographic studies of optimized blend**

Parameters	optimized blend
Arrival Time (min)	$3.50 \pm 0.01$
Degree of softening(BU)	$30.00 \pm 1.15$
Water absorption capacity (%)	$65.4 \pm 1.31$
Dough development time (min)	$5.51 \pm 0.09$
Stability (min)	$2.13 \pm 0.05$
Mixing Tolerance index (BU)	$52.84 \pm 1.18$

Values are presented as mean $\pm$ standard deviation

#### 4.2.4 Pasting properties of optimized blend.

The results of pasting properties of optimized rice and wheat blend is given in Table 4.27. Analysis of data indicated that the peak ( $1845.00 \pm 2.54$ ), hold ( $1448.00 \pm 1.38$ ), final ( $2293.00 \pm 3.21$ ) and setback viscosities ( $845.00 \pm 1.05$ ) were increased significantly ( $p < 0.01$ ) whereas pasting time ( $6.91 \pm 0.01$ ), pasting temperature ( $87.23 \pm 1.10$ ) and breakdown viscosity ( $397.00 \pm 1.27$ ) were significantly ( $p < 0.01$ ) decreased with rice flour incorporation.

**Table 4.27: Pasting properties of optimized blend**

Parameters	optimized blend
Pasting Time (min)	$6.91 \pm 0.01$
Peak Viscosity (cP)	$1845.00 \pm 2.54$
Hold Viscosity (cP)	$1448.00 \pm 1.38$
Setback Viscosity (cP)	$845.00 \pm 1.05$
Final Viscosity (cP)	$2293.00 \pm 3.21$
Breakdown Viscosity (cP)	$397.00 \pm 1.27$
Pasting Temperature ( $^{\circ}\text{C}$ )	$87.23 \pm 1.10$

Values are presented as mean $\pm$ standard deviation

#### 4.2.5 Physico-chemical properties of low-gluten flat bread

The final product (Plate 3) obtained after optimizing the processing conditions were analyzed for physicochemical properties and results are depicted in Table 4.28. The moisture content ( $32.1\pm 3.12$ ), crude fibre ( $2.46\pm 1.29$ ), crude fat ( $2.12\pm 1.08$ ), ash ( $1.64\pm 0.06$ ) and carbohydrate contents ( $54.88\pm 3.89$ ) of developed LGFB was higher while a significant decrease in protein content ( $6.91\pm 1.19$ ) was observed in developed LGFB with respect to wheat flour. Total sugars ( $6.71\pm 1.12$ ) and reducing sugars ( $0.64\pm 0.02$ ) was found to increase while non-reducing sugars ( $6.07\pm 1.11$ ) was found to decrease in developed LGFB with respect to wheat flour. Amylose ( $26.64\pm 2.38$ ), and resistant starch ( $7.32\pm 1.74$ ) was found to increase, whereas, total starch ( $69.15\pm 2.84$ ) and damaged starch ( $7.57\pm 1.11$ ) was found to decrease in developed LGFB with respect to wheat flour. The wet and dry gluten of developed LGFB was found to be markedly lower with respect to wheat flour.

**Table 4.28: Physicochemical properties of optimized low-gluten flat bread**

Parameters	Low gluten flat bread.
Moisture (%)	$32.1\pm 3.12$
Crude Fat (%)	$2.12\pm 1.08$
Crude Protein (%)	$6.91\pm 1.19$
Ash (%)	$1.64\pm 0.06$
Crude Fibre (%)	$2.46\pm 1.29$
Carbohydrates (%)	$54.88\pm 3.89$
Total Sugars (%)	$6.71\pm 1.12$
Reducing sugars (%)	$0.64\pm 0.02$
Non-reducing sugars (%)	$6.07\pm 1.11$
<b>Starch digestion profile</b>	
Amylose (%)	$26.64\pm 2.38$
Amylopectin (%)	$73.36\pm 3.91$
Total starch (%)	$69.15\pm 2.84$
Resistant starch (%)	$7.32\pm 1.74$
Damaged starch(%)	$7.57\pm 1.11$
<b>Gluten content</b>	
Wet gluten (%)	$8.37\pm 1.14$
Dry gluten (%)	$1.89 \pm 0.05$

Values are presented as mean±standard deviation



**Plate 3: Low gluten rice flour incorporated wheat flat bread (Optimized Product)**

#### 4.2.6 Mineral analysis

The mineral analysis of the optimized developed low-gluten flat bread (LGFB) is given in Table 4.29. Significant increase in mineral profile was observed during bread making process with respect to wheat flour.

**Table 4.29: Mineral profile of optimized low-gluten flat bread.**

Parameters	Low gluten flat bread
Calcium (mg/100g)	47.10±2.10
Sodium (mg/100g)	112.40±3.50
Phosphorous (mg/100g)	98.50±2.90
Iron (mg/100g)	4.60±1.20
Zinc (mg/100g)	3.20±1.10

Values are presented as mean±standard deviation

#### 4.2.7 Texture Profile analysis of low-gluten flat bread

The results of texture profile analysis of optimized developed low-gluten flatbread are depicted in Table 4.30. Hardness (8.20±1.62), gumminess (5.48±1.20) and chewiness (4.97±1.13) was lower whereas, cohesiveness (0.71±0.06) and springiness (0.85±0.09) was higher with rice flour incorporation in developed LGFB.

**Table 4.30: Texture profile analysis of low-gluten flat bread (LGFB)**

Parameters	Low-gluten flat bread
Hardness (N)	8.20±1.62
Cohesiveness	0.71±0.06
Springiness (mm)	0.85±0.09
Gumminess (N)	5.48±1.20
Chewiness (N)	4.97±1.13

Values are presented as mean±standard deviation

#### 4.2.8 Sensory evaluation of low-gluten flat bread

Results related to sensory characteristics viz. appearance, colour texture, flavor, chewability, mouthfeel and overall acceptability of optimized low-gluten flat bread are shown in Table (4.31). Higher score was rated by the panelists for texture, flavor and overall acceptability in developed low-gluten flat bread.

**Table 4.31: Sensory evaluation of low-gluten flat bread**

Parameters	Low-gluten flat bread
Appearance	4.20 ±0.21
Colour	4.12±0.14
Flavor	3.80±0.04
Texture	4.43±0.51
Chewability	3.69±0.02
Mouthfeel	4.17±0.32
Overall acceptability	4.06±0.98

Values are presented as mean±standard deviation

#### 4.2.9 Bread parameters

The results of bread parameters of optimized developed low-gluten flat bread are depicted in Table 4.32. Analysis of results revealed that thickness (8.55±0.06) weight (62.03±2.41), and yield (135.53±3.63) was found higher whereas, width (128.25±3.40), spread ratio (15.0±0.08), volume index (1.54±0.01), specific volume (3.95±0.04), puffiness (23.85±1.13), and oven spring (1.52±0.02) was lower in developed LGFB with rice flour incorporation.

**Table 4.32: Bread parameters of low gluten flat bread.**

Parameters	Low-gluten flat bread.
Spread ratio(W/T)	15.0±0.08
Width (mm)	128.25±3.40
Thickness (mm)	8.55±0.06
Weight(g)	62.03±2.41
Volume index (cm)	1.54±0.01
Specific volume (cm <sup>3</sup> /g)	3.95±0.04
Oven spring (cm)	1.52±0.02
Puffiness (%)	23.85±1.13
Yield (%)	135.53±3.63

Values are presented as mean±standard deviation

**4.3 Experiment III: To study the effect of hydrocolloids on the quality and storage stability of optimized low gluten flat bread (LGFB)**

Optimized low gluten flat breads were incorporated with three different hydrocolloids SSL (sodium stearyl-2-lactylate), GG (guar gum) and CMC (carboxymethyl cellulose) at a concentration of 0.3-0.9% and were studied for following physicochemical parameters.(Plate 4, 5 and 6).

**4.3.1 Proximate composition:**

**4.3.1.1 Moisture content**

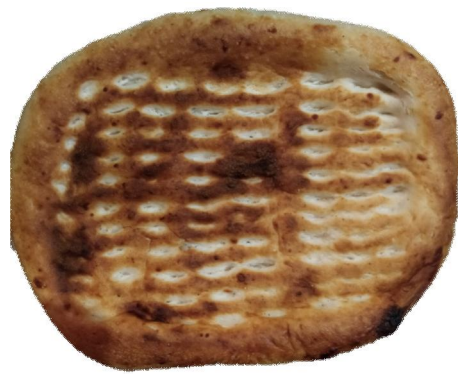
The data regarding the effect of different hydrocolloids (Sodium stearyl lactylate-SSL, Guargum-GG and carboxymethyl cellulose-CMC), hydrocolloids concentration (0.3%, 0.6% and 0.9%) and storage period of 8 days on moisture content of optimized flat bread is given in Table 4.33. Analysis of data depicted that moisture content of optimized low- gluten flat bread (32.01%) increased with increase in hydrocolloids incorporation upto 0.6% . However, more increase was noticed in CMC incorporated flat bread (34.10%) at initial day of storage. It was further noticed that at 0 days of storage, moisture content decreased after further incorporation of hydrocolloids from 0.6% to 0.9%, whereas, more decrease was noticed in SSL incorporated flat bread (30.70%). Moreover, moisture content of optimized flat bread decreased with increase in storage days and more decrease was noticed in SSL incorporated flat bread (27.30%) at 0.9% concentration during 8 days of storage period.

**Table 4.33: Effect of hydrocolloids, storage days on moisture content of low- gluten flat bread**

Storage period (Days)	Hydrocolloids												Mean	Factor
	0.3%				0.6%				0.9%					
	SSL	GG	CMC	Sub Mean	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub mean		
0	30.50	32.56	33.20	<b>32.08</b>	31.20	32.90	34.10	<b>32.73</b>	30.70	33.50	33.90	<b>32.70</b>	32.50	SSL=29.44 GG=30.73 CMC=32.08
2	30.0	31.32	32.30	<b>31.20</b>	30.71	31.05	33.18	<b>31.64</b>	29.80	32.03	32.23	<b>31.35</b>	31.40	
4	29.10	30.03	31.80	<b>30.31</b>	30.30	30.55	32.68	<b>31.17</b>	29.50	31.00	31.73	<b>30.74</b>	30.74	
6	28.60	29.62	31.03	<b>29.75</b>	29.50	29.98	32.58	<b>30.68</b>	28.10	30.58	31.48	<b>30.05</b>	30.16	
8	28.10	28.68	29.88	<b>28.88</b>	28.20	28.13	30.97	<b>29.10</b>	27.30	29.14	30.18	<b>28.87</b>	28.95	
Mean	<b>29.26</b>	<b>30.44</b>	<b>31.64</b>	<b>30.44</b>	<b>29.98</b>	<b>30.52</b>	<b>32.70</b>	<b>31.06</b>	<b>29.08</b>	<b>31.25</b>	<b>31.90</b>	<b>30.74</b>		

SSL: (sodium stearyl-2-lactylate), GG: (guar gum) and CMC:(carboxymethyl cellulose)

<b>C.D (p&lt;0.05) Days</b>	=	0.279
Hydrocolloid	=	0.216
C=Concentration	=	0.216
Days × Hydrocolloid	=	0.243
Days × Concentration	=	0.495
Hydrocolloid × Concentration	=	0.375;
Days × Hydrocolloid × Concentration	=	0.738



**Control**



**0.3% GG**

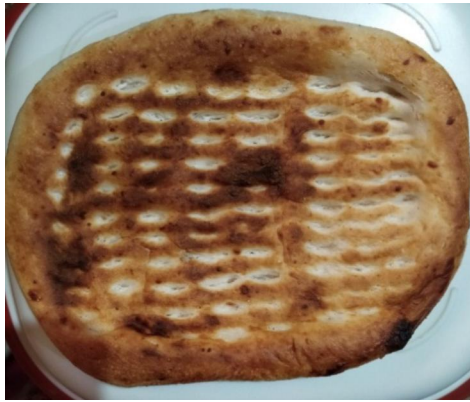


**0.6% GG**



**0.9% GG**

**Plate 4: Guar gum (GG) incorporated low gluten flat breads at a concentration of 0.3-0.9%**



**Control**



**0.3% CMC**



**0.6% CMC**

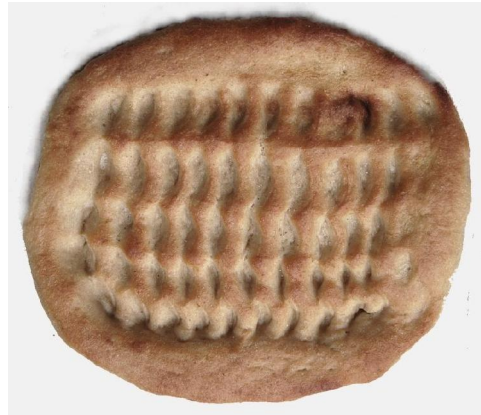


**0.9% CMC**

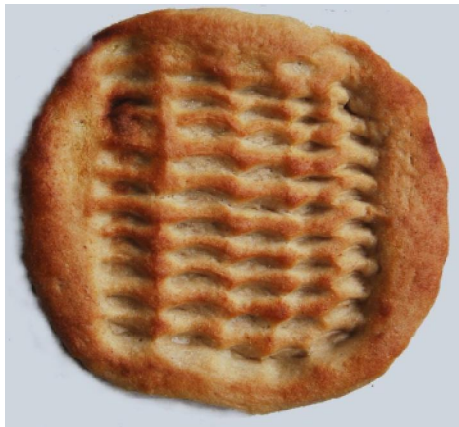
**Plate 5: Carboxymethyl cellulose (CMC) incorporated low gluten flat breads at a concentration of 0.3-0.9%**



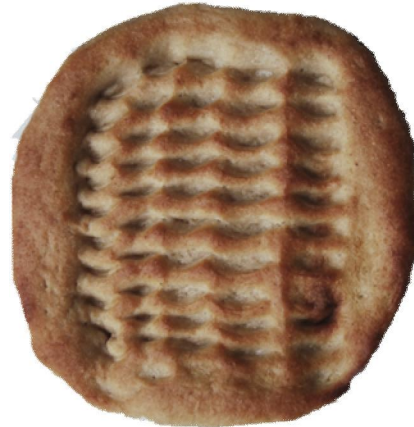
**Control**



**0.3% SSL**



**0.6% SSL**



**0.9% SSL**

**Plate 6: Sodium stearoyl-2-lactylate) (SSL) incorporated low gluten flat breads at a concentration of 0.3-0.9%**

#### **4.3.1.2 Crude Fat**

The data recorded for crude fat incorporated with different hydrocolloids (Sodium stearoyl-2 lactylate-SSL, Guargum-GG and carboxymethyl cellulose-CMC) at (0.3%, 0.6% and 0.9%) concentrations during storage for 8 days are presented in Table (4.34) Data analysis indicated that, with increase in concentration of hydrocolloids from 0.3 to 0.9%, crude fat content of optimized flat bread decreased in GG and CMC incorporated optimized low- gluten flat breads except in SSL incorporated flat bread where increase in crude fat was noticed with increase in hydrocolloid concentration. The values ranged from (2.40 to 2.30%) in GG incorporated optimized low-gluten flat bread; and (2.42 to 2.38%) in CMC incorporated optimized flat bread respectively. However the values in SSL incorporated optimized flat bread ranged from (2.33to 2.40 %) at 0.3 to 0.9 concentration. Further more crude fat decreased from 0 day to 8<sup>th</sup> day of storage from 2.40 to 2.28, in SSL, 2.30 to 2.10 in GG and 2.38 to 2.26 in CMC incorporated flat breads at 0.9% concentration .

#### **4.3.1.3 Crude Fibre**

Analysis of data for crude fibre of optimized low gluten flat breads incorporated with different hydrocolloids (Sodium stearoyl-2 lactylate-SSL, Guargum-GG and carboxymethyl cellulose-CMC) at (0.3%, 0.6% and 0.9%) concentrations during storage for 8 days are presented in Table (4.35). Data analysis indicated that, with increase in concentration of hydrocolloids from 0.3 to 0.9%, crude fibre content of optimized low- gluten flat bread increased in SSL,GG and CMC incorporated optimized flat breads. However higher crude fibre content was found in CMC incorporated flat bread at 0.9% concentration (2.34%) at 0 day of storage.while as lower crude fibre was observed in SSL incorporated flat bread (2.28%) at same concentration. Further more, it was observed that crude fibre decreases from 0 to 8 days of storage and the values ranged from (2.28 to 2.18%) in SSL;(2.32 to 2.21 %)GG and (2.34to 2.22%) CMC incorporated optimized low- gluten flat breads respectively.

**Table 4.34: Effect of hydrocolloids, storage days on crude fat content of low gluten flat bread**

<b>Storage Period (Days)</b>	<b>0.3%</b>				<b>0.6%</b>				<b>0.9%</b>				<b>Overall Mean</b>	<b>Factor</b>
	<b>SSL</b>	<b>GG</b>	<b>CMC</b>	<b>Sub Mean</b>	<b>SSL</b>	<b>GG</b>	<b>CMC</b>	<b>Sub mean</b>	<b>SSL</b>	<b>GG</b>	<b>CMC</b>	<b>Sub mean</b>		
<b>0</b>	2.33	2.40	2.42	<b>2.38</b>	2.38	2.38	2.40	<b>2.38</b>	2.40	2.30	2.38	<b>2.36</b>	<b>2.37</b>	SSL=2.15 GG=2.13 CMC=2.17
<b>2</b>	2.29	2.38	2.38	<b>2.35</b>	2.36	2.32	2.37	<b>2.35</b>	2.37	2.25	2.33	<b>2.31</b>	<b>2.34</b>	
<b>4</b>	2.27	2.30	2.35	<b>2.30</b>	2.32	2.30	2.32	<b>2.31</b>	2.33	2.22	2.30	<b>2.27</b>	<b>2.29</b>	
<b>6</b>	2.25	2.28	2.32	<b>2.28</b>	2.29	2.27	2.30	<b>2.28</b>	2.30	2.20	2.28	<b>2.26</b>	<b>2.27</b>	
<b>8</b>	2.21	2.25	2.29	<b>2.25</b>	2.27	2.25	2.29	<b>2.27</b>	2.28	2.10	2.26	<b>2.21</b>	<b>2.24</b>	
<b>Mean</b>	<b>2.27</b>	<b>2.32</b>	<b>2.35</b>	<b>2.31</b>	<b>2.32</b>	<b>2.30</b>	<b>2.33</b>	<b>2.31</b>	<b>2.33</b>	<b>2.21</b>	<b>2.31</b>	<b>2.28</b>		

SSL: (sodium stearyl-2-lactylate), GG: (guar gum) and CMC:(carboxymethyl cellulose)

<b>C.D(p&lt;0.05)</b> Days	=	0.013
Hydrocolloid	=	0.010
Concentration	=	0.022
Days × Hydrocolloid	=	0.022
Hydrocolloid × Concentration	=	0.017
Days × Hydr × Conc	=	0.038

**Table 4.35: Effect of hydrocolloids, storage days on crude fibre content of low gluten flat bread**

Storage Period	0.3%				0.6%				0.9%					
(Days)	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub mean	Mean	Factor
0	2.22	2.25	2.27	<b>2.26</b>	2.24	2.29	2.30	<b>2.28</b>	2.28	2.32	2.34	<b>2.29</b>	2.27	SSL=2.20 GG=2.24 CMC=2.25
2	2.20	2.22	2.25	<b>2.20</b>	2.23	2.27	2.29	<b>2.26</b>	2.26	2.29	2.31	<b>2.26</b>	2.24	
4	2.19	2.20	2.23	<b>2.22</b>	2.20	2.24	2.24	<b>2.22</b>	2.23	2.27	2.29	<b>2.25</b>	2.23	
6	2.16	2.18	2.21	<b>2.19</b>	2.17	2.20	2.22	<b>2.19</b>	2.20	2.24	2.27	<b>2.22</b>	2.20	
8	2.14	2.17	2.18	<b>2.17</b>	2.15	2.16	2.20	<b>2.17</b>	2.18	2.21	2.22	<b>2.19</b>	2.17	
<b>Mean</b>	<b>2.18</b>	<b>2.20</b>	<b>2.22</b>	<b>2.22</b>	<b>2.20</b>	<b>2.23</b>	<b>2.25</b>	<b>2.22</b>	<b>2.23</b>	<b>2.26</b>	<b>2.28</b>	<b>2.24</b>		

SSL: (sodium stearyl-2-lactylate), GG: (guar gum) and CMC:(carboxymethyl cellulose)

**C.D(p<0.05)** Days = 0.026  
 Hydrocolloid = 0.020  
 C=Concentration = Ns  
 Days × Hydrocolloid = NS  
 Days × Concentration = 0.026  
 Hydrocolloid × Concentration = 0.035  
 Days × Hydr × Conc = NS

#### **4.3.1.4 Crude protein**

The data regarding the effect of different hydrocolloids (Sodium stearyl lactylate-SSL, Guargum-GG and carboxymethyl cellulose-CMC), hydrocolloids concentration (0.3%, 0.6% and 0.9%) and storage days on crude protein of optimized low gluten flat bread is given in Table (4.36). Analysis of data indicated that at 0 days of storage, crude protein content of optimized low gluten flat bread decreased with increase in hydrocolloids incorporation from 8.75 to 8.70 in SSL incorporated fat bread, 8.79% to 8.74% in GG incorporated flat bread and 8.85% to 8.80% in CMC incorporated flat bread at 0.3, 0.6 and 0.9% concentrations, respectively. Furthermore, crude protein content decreased with increase in storage days, however more decrease was noticed in GG incorporated flat bread (8.47%) after 8 days of storage.

#### **4.3.1.5 Ash**

Analysis of data for ash of optimized low gluten flat breads incorporated with different hydrocolloids (Sodium stearyl-2 lactylate-SSL, Guargum-GG and carboxymethyl cellulose-CMC) at (0.3%, 0.6% and 0.9%) concentrations during storage for 8 days are depicted in Table (4.37) Data analysis indicate that, with increase in concentration of hydrocolloids from 0.3 to 0.9%, increased in ash content was noticed in SSL,GG and CMC incorporated optimized low- gluten flat breads. However higher ash content was found in CMC incorporated flat bread at 0.9% concentration (1.65%) at 0 day of storage.while as lower crude fibre % was observed in SSL incorporated flat bread(1.59%) at same concentration. Further more, it was observed that ash decreases from 0 to 8 days of storage, more decrease was noticed in SSL incorporated flat bread from (1.59 to 1.47 %) and less decrease. was noticed in CMC incorporated flat bread (1.65 to 1.53%) respectively.

**Table 4.36: Effect of hydrocolloids, storage days on crude protein content of low -gluten flat bread**

Storage Period	0.3%				0.6%				0.9%					
(Days)	SSL	GG	CMC	Sub Mean	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub mean	Mean	Factor
0	8.75	8.79	8.85	<b>8.79</b>	8.72	8.75	8.83	<b>8.76</b>	8.70	8.74	8.80	<b>8.74</b>	<b>8.76</b>	SSL=8.67 GG=8.51 CMC=8.56
2	8.73	8.71	8.77	<b>8.73</b>	8.71	8.70	8.73	<b>8.71</b>	8.69	8.68	8.71	<b>8.69</b>	<b>8.71</b>	
4	8.70	8.68	8.75	<b>8.71</b>	8.68	8.65	8.72	<b>8.69</b>	8.66	8.63	8.70	<b>8.66</b>	<b>8.68</b>	
6	8.68	8.65	8.71	<b>8.68</b>	8.65	8.63	8.69	<b>8.65</b>	8.62	8.60	8.67	<b>8.63</b>	<b>8.65</b>	
8	8.60	8.50	8.65	<b>8.58</b>	8.57	8.48	8.55	<b>8.53</b>	8.50	8.47	8.53	<b>8.49</b>	<b>8.53</b>	
Mean	<b>8.69</b>	<b>8.66</b>	<b>8.74</b>	<b>8.69</b>	<b>8.66</b>	<b>8.55</b>	<b>8.70</b>	<b>8.66</b>	<b>8.61</b>	<b>8.62</b>	<b>8.68</b>	<b>8.65</b>		

SSL: (sodium stearyl-2-lactylate),GG: (guar gum) and CMC:(carboxymethyl cellulose)

<b>C.D(p&lt;0.05)</b> Days	=	0.028
Hydrocolloid	=	0.022
Concentration	=	0.049
Days × Hydrocolloid	=	0.049
Daysx concentration	=	0.022
Hydrocolloid × Concentration	=	0.049
Days x Hydrocolloid × Concentration	=	0.048

**Table 4.37: Effect of hydrocolloids, storage days on ash content of low gluten flat bread.**

Storage Period	0.3%				0.6%				0.9%					
(Days)	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub mean	Mean	Factor
0	1.54	1.55	1.57	<b>1.55</b>	1.57	1.59	1.60	<b>1.58</b>	1.59	1.63	1.65	<b>1.62</b>	<b>1.58</b>	SSL=1.51 GG=1.52 CMC=1.54
2	1.52	1.50	1.53	<b>1.51</b>	1.55	1.55	1.57	<b>1.55</b>	1.56	1.59	1.60	<b>1.58</b>	<b>1.55</b>	
4	1.50	1.49	1.50	<b>1.49</b>	1.51	1.52	1.55	<b>1.52</b>	1.53	1.55	1.58	<b>1.55</b>	<b>1.52</b>	
6	1.48	1.48	1.50	<b>1.48</b>	1.46	1.50	1.51	<b>1.49</b>	1.49	1.53	1.58	<b>1.53</b>	<b>1.50</b>	
8	1.46	1.45	1.47	<b>1.46</b>	1.42	1.47	1.49	<b>1.46</b>	1.47	1.49	1.53	<b>1.49</b>	<b>1.47</b>	
<b>Mean</b>	<b>1.50</b>	<b>1.49</b>	<b>1.51</b>	<b>1.50</b>	<b>1.50</b>	<b>1.52</b>	<b>1.54</b>	<b>1.52</b>	<b>1.52</b>	<b>1.55</b>	<b>1.58</b>	<b>1.55</b>		

SSL: (sodium stearyl-2-lactylate), GG: (guar gum) and CMC:(carboxymethyl cellulose)

**C.D(p<0.05)** Days = NS  
Hydrocolloid = NS  
C=Concentration = NS  
Days × Hydrocolloid = NS  
Days × Concentration = NS  
Days x Hydrocolloidx Concentration = NS

#### **4.1.1.6 Carbohydrate :**

The data regarding the effect of different hydrocolloids (Sodium stearyl lactylate-SSL, Guargum-GG and carboxymethyl cellulose-CMC), hydrocolloids concentration (0.3%, 0.6% and 0.9%) and storage days on carbohydrate content of optimized low gluten flat bread is illustrated in Table (4.38). Data analysis revealed that, with increase in concentration of hydrocolloids from 0.3 to 0.9%, carbohydrate content of optimized low-gluten flat bread increased in SSL, GG and CMC incorporated optimized flat breads. However higher carbohydrate content was found in CMC incorporated flat bread at 0.9% concentration (53.74%) at 0 day of storage. while as lower carbohydrate (45.39%) was observed in SSL incorporated flat bread at similar concentration. However, it was observed that with increase in storage days from 0 to 8 days, carbohydrate content was decreased. whereas as, higher decrease was found in SSL incorporated flat bread from (45.39 to 40.61%) and lesser decline was noticed in CMC incorporated flat bread (53.74 to 45.23%) .

**Table 4.38: Effect of hydrocolloids, storage days on carbohydrate content of low gluten flat bread.**

Storage Period	0.3%				0.6%				0.9%					
(Days)	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub Mean	Mean	Factor
0	46.12	51.85	50.68	<b>49.63</b>	45.61	52.09	51.58	<b>49.68</b>	45.39	52.51	53.74	<b>49.88</b>	<b>49.73</b>	SSL=44.124 GG=46.188 CMC=47.282
2	45.54	45.90	47.19	<b>46.21</b>	44.81	46.12	47.23	<b>45.98</b>	43.80	46.84	48.04	<b>46.56</b>	<b>46.25</b>	
4	45.01	44.28	46.32	<b>45.20</b>	44.17	44.82	46.45	<b>45.14</b>	43.60	45.22	47.23	<b>45.41</b>	<b>45.20</b>	
6	44.07	44.15	45.84	<b>44.68</b>	43.71	44.66	46.11	<b>44.49</b>	43.21	45.18	47.13	<b>45.17</b>	<b>44.83</b>	
8	42.47	42.39	44.18	<b>43.01</b>	41.72	42.84	44.31	<b>42.95</b>	40.61	43.97	45.23	<b>43.93</b>	<b>43.30</b>	
Mean	43.96	<b>45.97</b>	<b>47.08</b>	<b>45.67</b>	<b>44.64</b>	<b>45.98</b>	<b>47.84</b>	<b>46.15</b>	<b>43.76</b>	<b>46.61</b>	<b>48.84</b>	<b>46.19</b>		

SSL: (sodium stearyl-2-lactylate), GG: (guar gum) and CMC:(carboxymethyl cellulose)

<b>C.D(p&lt;0.05)</b> Days	=	0.182
Hydrocolloid	=	0.141
Concentration	=	0.141
Days × Hydrocolloid	=	0.315
Days × Concentration	=	0.315
Hydr × Concentration	=	0.244
Days × Hydr × Conc	=	0.545

## **4.3.2 Texture profile analysis of hydrocolloid incorporated low- gluten flat breads during storage**

### **4.3.2.1 Hardness**

Table 4.39 to Table 4.43 show the effect of hydrocolloids on textural properties of low gluten optimized flat breads. The data regarding the effect of different hydrocolloids (Sodium stearyl lactylate-SSL, Guargum-GG and carboxymethyl cellulose-CMC), hydrocolloids concentration (0.3%, 0.6% and 0.9%) and storage days on hardness of optimized flat bread is depicted in Table 4.39. Analysis of data depicted that hardness of optimized low- gluten flat bread decreased with increase in hydrocolloids incorporation upto 0.6% concentration, however, minimum hardness was noticed in GG incorporated flat bread (8.19 N) at 0 days of storage and maximum hardness was noticed in CMC incorporated flat bread (8.43N) at similar concentration. It was further noticed that further incorporation of hydrocolloids from 0.6% to 0.9%, resulted in increase in hardness values. Moreover, hardness of optimized low gluten flat bread increased with increase in storage days. The minimum and maximum hardness of 8.42 and 10.22 N was recorded in CMC incorporated flat bread from 0 to 8<sup>th</sup> day of storage followed by GG (8.19 to 9.81N).

### **4.3.2.2 Cohesiveness**

Table 4.40 depicts the analysis of data for cohesiveness of optimized low gluten flat breads incorporated with different hydrocolloids (Sodium stearyl-2 lactylate-SSL, Guargum-GG and carboxymethyl cellulose-CMC) at (0.3%, 0.6% and 0.9%) concentrations during storage for 8 days. Data analysis indicate that, with increase in concentration of hydrocolloids from 0.3 to 0.9%, cohesiveness increased significantly ( $p \leq 0.05$ ) in SSL, GG and CMC incorporated optimized low-gluten flat breads. However higher cohesiveness was found in CMC incorporated flat bread (0.73) at 0.9% concentration on 0 day of storage. while as lower cohesiveness was observed in CMC incorporated flat bread (0.68) at same concentration. Further more, it was observed that cohesiveness decreases with increase in storage days from 0 to 8<sup>th</sup> day. Cohesiveness decreased from 0.73 to 0.68 in (GG) flat bread and 0.68 to 0.66 in (CMC) incorporated flat bread respectively.

**Table 4.39: Effect of hydrocolloids, storage days on hardness of low-gluten flat bread**

Storage Period	0.3%				0.6%				0.9%					
	Days	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub Mean	Mean
0	8.270	8.380	8.440	<b>8.36</b>	8.200	8.193	8.433	<b>8.25</b>	8.230	8.240	8.420	<b>8.29</b>	<b>8.30</b>	SSL=9.04 GG=8.99 CMC=9.24
2	8.580	8.610	8.690	<b>8.62</b>	8.440	8.440	8.700	<b>8.52</b>	8.550	8.500	8.720	<b>8.59</b>	<b>8.58</b>	
4	9.030	8.960	9.380	<b>9.12</b>	8.990	8.790	9.160	<b>8.98</b>	9.04	8.850	9.200	<b>9.03</b>	<b>9.04</b>	
6	9.520	9.510	9.600	<b>9.54</b>	9.390	9.300	9.670	<b>9.45</b>	9.54	9.360	9.710	<b>9.53</b>	<b>9.51</b>	
8	10.010	10.030	10.120	<b>10.05</b>	9.980	9.810	10.180	<b>9.99</b>	9.99	9.88	10.22	<b>10.03</b>	<b>10.02</b>	
Mean	<b>9.08</b>	<b>9.09</b>	<b>9.24</b>	<b>9.14</b>	<b>8.99</b>	<b>8.90</b>	<b>9.22</b>	<b>9.04</b>	<b>9.07</b>	<b>8.96</b>	<b>9.25</b>	<b>9.09</b>		

SSL: (sodium stearyl-2-lactylate),GG: (guar gum) and CMC:(carboxymethyl cellulose)

<b>C.D(p&lt;0.05)</b> Days	=	0.045
Hydrocolloid	=	0.035
Concentration	=	0.025
Days × Hydrocolloid	=	0.078
Days × concentration	=	0.07
Hydrocolloidx Concentration	=	0.061
Days × Hydr × Conc	=	0.105

**Table 4.40: Effect of hydrocolloids, storage days on Cohesiveness of low gluten flat bread**

Storage Period (Days)	0.3%				0.6%				0.9%				Mean	Factor
	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub mean		
0	0.66	0.70	0.65	<b>0.67</b>	0.69	0.71	0.67	<b>0.68</b>	0.70	0.73	0.68	<b>0.70</b>	<b>0.68</b>	SSL= 0.69 GG= 0.66 CMC= 0.64
2	0.65	0.69	0.64	<b>0.66</b>	0.68	0.70	0.66	<b>0.68</b>	0.70	0.71	0.67	<b>0.69</b>	<b>0.67</b>	
4	0.64	0.68	0.63	<b>0.65</b>	0.67	0.69	0.65	<b>0.67</b>	0.69	0.70	0.66	<b>0.68</b>	<b>0.66</b>	
6	0.63	0.67	0.62	<b>0.64</b>	0.65	0.68	0.64	<b>0.65</b>	0.68	0.69	0.65	<b>0.67</b>	<b>0.65</b>	
8	<b>0.62</b>	<b>0.66</b>	<b>0.61</b>	<b>0.63</b>	<b>0.64</b>	<b>0.67</b>	<b>0.63</b>	<b>0.64</b>	<b>0.67</b>	<b>0.68</b>	<b>0.66</b>	<b>0.67</b>	<b>0.64</b>	

SSL: (sodium stearyl-2-lactylate),GG: (guar gum) and CMC:(carboxymethyl cellulose)

<b>C.D(p&lt;0.05)</b> Days	=	0.006
Hydrocolloid	=	0.004
Concentration	=	0.003
Days × Hydrocolloid	=	0.01
Days × Concentration	=	0.009
Hydrocolloid × Concentration	=	0.007
Days × Hydr × Conc	=	0.013

#### 4.3.2.3 Springiness

Table 4.41 represents the effect of hydrocolloids on springiness of optimized low gluten flat bread. Analysis revealed that springiness increased significantly ( $p \leq 0.05$ ) with incorporation of hydrocolloids (Sodium stearoyl-2 lactylate-SSL, Guargum-GG and carboxymethyl cellulose-CMC) at (0.3%, 0.6% and 0.9%) concentrations during storage for 8 day. More increase in springiness was observed in CMC incorporated flat bread at 0.9% concentration. than SSL and GG flat breads. Springiness increased from 0.88 to 0.90mm in (CMC flat bread); 0.87 to 0.89 mm in (GG flat bread) and 0.86 to 0.88 mm in (SSL flat bread) respectively. Moreover springiness decreased significantly during 0 to 8<sup>th</sup> day of storage. More decrease was noticed in SSL incorporated flat bread from (0.88 to 0.84 mm) at 0.9%.whereas, less decrease was examined in CMC flat bread from (0.90 to 0.86 mm) at similar concentration.

#### 4.3.2.4 Gumminess

Table 4.42 depicts the analysis of data for gumminess of optimized low gluten flat breads incorporated with different hydrocolloids (Sodium stearoyl-2 lactylate-SSL, Guargum-GG and carboxymethyl cellulose-CMC) at (0.3%, 0.6% and 0.9%) concentrations during storage for 8 days. Data analysis indicate that, with increase in concentration of hydrocolloids from 0.3 to 0.9%, gumminess decreased significantly ( $p \leq 0.05$ ) in SSL, GG and CMC incorporated optimized flat breads. Gumminess decreases from (5.92 to 5.78 N) in SSL flat bread (5.72 to 5.48N) in GG flat bread (5.83 to 5.53N) in CMC flat bread. However, Gumminess increased significantly during 0 to 8<sup>th</sup> day of storage. Maximum increase in gumminess was noticed in SSL incorporated flat bread from (5.78 to 6.60N) at 0.9%.whereas, minimum increase in gumminess was examined in GG flat bread (5.48 to 6.17N) at similar concentration.

**Table 4.41: Effect of hydrocolloids, storage days on springiness of low gluten flat bread**

Storage Period (Days)	0.3%				0.6%				0.9%				Mean	Factor
	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub mean		
0	0.86	0.87	0.88	<b>0.87</b>	0.87	0.88	0.89	<b>0.88</b>	0.88	0.89	0.90	<b>0.89</b>	<b>0.88</b>	<b>SSL=0.85</b> <b>GG=0.86</b> <b>CMC=0.87</b>
2	0.85	0.86	0.87	<b>0.86</b>	0.86	0.87	0.88	<b>0.87</b>	0.87	0.88	0.89	<b>0.88</b>	<b>0.87</b>	
4	0.84	0.85	0.86	<b>0.85</b>	0.85	0.86	0.87	<b>0.86</b>	0.86	0.87	0.88	<b>0.87</b>	<b>0.86</b>	
6	0.83	0.84	0.85	<b>0.84</b>	0.84	0.85	0.86	<b>0.85</b>	0.85	0.86	0.87	<b>0.86</b>	<b>0.85</b>	
8	0.82	0.83	0.84	<b>0.83</b>	0.83	0.84	0.85	<b>0.84</b>	0.84	0.85	0.86	<b>0.85</b>	<b>0.84</b>	
Mean	<b>0.84</b>	<b>0.85</b>	<b>0.86</b>	<b>0.85</b>	<b>0.85</b>	<b>0.86</b>	<b>0.87</b>	<b>0.86</b>	<b>0.86</b>	<b>0.87</b>	<b>0.88</b>	<b>0.87</b>		

SSL: (sodium stearyl-2-lactylate),GG: (guar gum) and CMC:(carboxymethyl cellulose)

<b>C.D(p&lt;0.05)</b> Days	=	0.010
Hydrocolloid	=	0.008
C=Concentration	=	0.004
Days × Hydrocolloid	=	0.018
Days × concentration	=	0.014
Hydrocolloid × Concentration	=	0.012
Days × Hydr × Conc	=	0.022

**Table 4.42: Effect of hydrocolloids, storage days on gumminess of low-gluten flat bread**

Storage Period (Days)	0.3%				0.6%				0.9%				Mean	Factor
	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub Mean	SSL	GG	CMC	Sub mean		
0	5.92	5.72	5.83	<b>5.82</b>	5.79	5.64	5.65	<b>5.69</b>	5.78	5.48	5.53	<b>5.60</b>	<b>5.70</b>	SSL=6.22 GG=5.96 CMC=5.96
2	6.07	5.84	5.94	<b>5.95</b>	5.90	5.73	5.74	<b>5.79</b>	5.92	5.56	5.59	<b>5.69</b>	<b>5.81</b>	
4	6.32	6.07	6.10	<b>6.16</b>	6.14	5.90	5.95	<b>5.99</b>	6.14	5.73	5.73	<b>5.86</b>	<b>6.00</b>	
6	6.56	6.31	6.36	<b>6.41</b>	6.39	6.04	6.18	<b>6.20</b>	6.37	5.95	6.01	<b>6.11</b>	<b>6.24</b>	
8	6.79	6.74	6.61	<b>6.71</b>	6.68	6.27	6.41	<b>6.45</b>	6.60	6.17	6.21	<b>6.32</b>	<b>6.49</b>	
Mean	<b>6.33</b>	<b>6.13</b>	<b>6.16</b>	<b>6.21</b>	<b>6.18</b>	<b>5.91</b>	<b>5.98</b>	<b>6.02</b>	<b>6.16</b>	<b>5.77</b>	<b>5.81</b>	<b>5.91</b>		

SSL: (sodium stearyl-2-lactylate), GG: (guar gum) and CMC:(carboxymethyl cellulose)

<b>C.D(p&lt;0.05)</b> Days	=	0.016
Hydrocolloid	=	0.013
C=Concentration	=	0.012
Days × Hydrocolloid	=	0.028
Days × concentration	=	0.028
Hydrocolloidx Concentration	=	0.024;
Days × Hydr × Conc	=	0.049.

#### **4.3.2.5 Chewiness**

Table 4.43 depicts the data regarding the effect of different hydrocolloids (Sodium stearoyl lactylate-SSL, Guar gum-GG and carboxymethyl cellulose-CMC), hydrocolloids concentration (0.3%, 0.6% and 0.9%) and storage days on chewiness of optimized low-gluten flat bread. Chewiness is directly related to hardness. Analysis revealed that chewiness of optimized low gluten flat bread decreased with increase in hydrocolloids incorporation from (5.15 to 5.03N) in SSL incorporated fat bread (5.01 to 4.86N) in GG incorporated flat bread and (5.03 to 4.87N) in CMC incorporated flat bread at 0.3, 0.6 and 0.9% concentrations, respectively. Furthermore, chewiness increased with increase in storage days, however more increase was observed in SSL incorporated flat bread from (5.03 to 5.54N) and less increase was noticed in GG incorporated flat bread from (4.86 to 5.27N) at 0.9% concentration.

#### **4.3.2.6 Instrumental colour:**

##### **4.3.2.6.1 Luminosity ( $L^*$ value)**

Table 4.44 to 4.46 showed effect of hydrocolloid on instrumental colour of optimized low gluten flat breads incorporated with different hydrocolloids (Sodium stearoyl lactylate-SSL, Guar gum-GG and carboxymethyl cellulose-CMC) at a concentration of (0.3%, 0.6% and 0.9%). Data analysis for luminosity ( $L^*$  value) (Table 4.44) showed that incorporation of hydrocolloids, concentration of hydrocolloids and storage period significantly ( $p < 0.05$ ) affected luminosity ( $L^*$  value) of low gluten optimized flat bread from 0.3 to 0.9% concentration. Increase in luminosity ( $L^*$  value) was noticed with addition of hydrocolloids. However, more increase in  $L^*$  value was observed from (48.55 to 48.95) in CMC incorporated flat and less increase was observed in SSL added bread (47.73 to 47.85) at 0.9% concentration. Further more, the luminosity ( $L^*$  value) decreased, during the entire storage period of 8 days. More decrease in  $L^*$  value was found in SSL bread from (47.85 to 43.73), whereas, less decrease was noticed in CMC added flat bread from (48.95 to 45.35) from 0 to 8<sup>th</sup> day of storage period.

**Table 4.43: Effect of hydrocolloids, storage days on Chewiness of low gluten flat bread**

Storage Period (Days)	0.3% Conc.				0.6% conc				0.9% conc			Sub mean	Mean	Factor
	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub mean	SSL	GG	CMC			
0	5.15	5.01	5.03	<b>5.06</b>	5.08	4.97	5.02	<b>5.02</b>	5.03	4.86	4.87	<b>4.92</b>	5.00	SSL=5.30 GG=5.12 CMC=5.17
2	5.22	5.11	5.08	<b>5.13</b>	5.15	5.01	5.05	<b>5.07</b>	5.13	4.95	4.99	<b>5.02</b>	5.07	
4	5.31	5.19	5.22	<b>5.24</b>	5.28	5.07	5.17	<b>5.17</b>	5.21	5.04	5.05	<b>5.10</b>	5.17	
6	5.51	5.28	5.36	<b>5.38</b>	5.43	5.22	5.32	<b>5.32</b>	5.33	5.13	5.17	<b>5.21</b>	5.30	
8	5.63	5.42	5.66	<b>5.57</b>	5.61	5.34	5.44	<b>5.46</b>	5.54	5.27	5.30	<b>5.37</b>	5.46	
Mean	5.36	5.20	5.27	<b>5.27</b>	5.30	5.12	5.20	<b>5.20</b>	5.25	5.05	5.07	<b>5.12</b>		

SSL: (sodium stearyl-2-lactylate), GG: (guar gum) and CMC:(carboxymethyl cellulose)

<b>C.D(p&lt;0.05)</b> Days	=	0.021
Hydrocolloid	=	0.017
Concentration	=	0.015
Days × Hydrocolloid	=	0.037
Days × concentration	=	0.036
Hydrocolloid × Concentration	=	0.032
Days × Hydr × Conc	=	0.052

**Table 4.44: Effect of hydrocolloids, storage days on Luminosity ( $L^*$  value) of low -gluten flat bread**

Storage Period (Days)	0.3%				0.6%				0.9%				Mean	Factor
	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub mean		
0	47.73	48.12	48.55	<b>48.13</b>	47.75	48.32	48.75	48.27	<b>47.85</b>	48.35	48.95	<b>48.38</b>	48.26	SSL=46.81 GG=46.19 CMC=47.20
2	47.70	48.03	47.70	<b>48.07</b>	47.72	48.25	48.65	48.20	<b>47.80</b>	48.30	48.85	<b>48.316</b>	48.19	
4	46.60	47.010	47.080	<b>46.89</b>	46.62	47.05	47.12	46.93	<b>46.730</b>	47.23	47.350	<b>47.10</b>	46.979	
6	45.09	46.850	46.95	<b>46.29</b>	45.12	47.01	47.05	46.39	<b>45.230</b>	47.12	47.250	<b>46.533</b>	46.40	
8	43.59	45.350	43.780	<b>44.24</b>	43.62	45.51	44.78	44.63	<b>43.730</b>	44.62	45.350	<b>44.900</b>	44.559	
<b>Mean</b>	<b>46.14</b>	<b>47.07</b>	<b>46.81</b>	<b>46.72</b>	<b>46.16</b>	<b>47.22</b>	<b>47.31</b>	<b>46.58</b>	<b>46.26</b>	<b>47.32</b>	<b>47.37</b>	<b>46.88</b>		

SSL: (sodium stearyl-2-lactylate),GG: (guar gum) and CMC:(carboxymethyl cellulose)

<b>CD(P&lt;0.05)</b> Days	=	0.027
Hydrocolloid	=	0.021
Concentration	=	0.021
Days × Hydrocolloid	=	0.047
Days × concentration	=	0.047
Hydrocolloid × Concentration	=	0.042
Days × Hydr × Conc	=	0.069

#### 4.3.2.6.2 Redness ( $a^*$ value)

Table 4.45 depicts the analysis of data for redness ( $a^*$  value) of optimized low - gluten flat breads incorporated with different hydrocolloids (Sodium stearoyl-2 lactylate-SSL, Guar gum-GG and carboxymethyl cellulose-CMC) at (0.3%, 0.6% and 0.9%) concentrations during storage period for 8 days. Data analysis indicate that, with increase in hydrocolloid incorporation from 0.3 to 0.9% concentration, redness ( $a^*$  value) was significantly ( $p < 0.05$ ) affected by hydrocolloid addition, Concentration levels and storage period. Decrease in redness ( $a^*$  value) was noticed with addition of hydrocolloids. However, less decrease in  $a^*$  value was observed from (4.00 to 3.90) in CMC incorporated flat, followed by (3.87 to 3.79) in GG flat bread and (3.82 to 3.70) in SSL incorporated flat bread. In addition, the redness ( $a^*$  value) increased during the entire storage period of 8 days. More increase in  $a^*$  value was noticed in CMC bread from (3.90 to 4.52), whereas, less increase was noticed in GG flat bread from (3.79 to 4.33) during the storage period from 0 to 8<sup>th</sup> day.

#### 4.3.2.6.3 Yellowness ( $b^*$ value)

Table 4.46 enlisted the effect of hydrocolloids on yellowness ( $b^*$  value) of optimized low gluten flat breads incorporated with different hydrocolloids (Sodium stearoyl lactylate-SSL, Guar gum-GG and carboxymethyl cellulose-CMC) at a concentration of (0.3%, 0.6% and 0.9%). Data analysis for yellowness ( $b^*$  value) showed that incorporation of hydrocolloids, concentration of hydrocolloids and storage period significantly ( $p < 0.05$ ) affected yellowness ( $b^*$  value) of low gluten optimized flat bread from 0.3 to 0.9% concentration. Decrease in ( $b^*$  value) was noticed with addition of hydrocolloids. However, more decrease in  $b^*$  value was observed from (23.75 to 23.05) in SSL incorporated flat and less decrease was observed in GG added bread (24.48 to 23.98) at 0.9% concentration. Further more, the yellowness ( $b^*$  value) decreased, during the entire storage period of 8 days. Yellowness ( $b^*$  value) decreased from (23.98 to 21.35) in GG flat bread (23.38 to 20.95) in CMC flat bread and from (23.05 to 20.43) in SSL flat bread from 0 to 8<sup>th</sup> days of storage period.

**Table 4.45: Effect of hydrocolloids, storage days on redness ( $a^*$  value) of low- gluten flat bread**

Storage Period (Days)	0.3%.				0.6%				0.9%				Mean	Factor
	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub mean		
0	3.820	3.870	4.000	<b>3.897</b>	3.750	3.800	3.970	<b>3.840</b>	3.700	3.790	3.900	<b>3.797</b>	<b>3.844</b>	SSL=4.27 GG=3.97 CMC=3.98
2	3.850	3.897	4.080	<b>3.942</b>	3.950	3.880	3.990	<b>3.940</b>	3.770	3.820	3.930	<b>3.840</b>	<b>3.907</b>	
4	3.900	3.950	4.570	<b>4.140</b>	3.970	3.920	4.080	<b>3.990</b>	3.790	3.890	4.010	<b>3.897</b>	<b>4.009</b>	
6	3.950	3.980	4.750	<b>4.227</b>	3.990	3.970	4.380	<b>4.113</b>	3.890	3.930	4.213	<b>4.011</b>	<b>4.117</b>	
8	4.450	4.380	5.050	<b>4.627</b>	4.490	4.370	4.680	<b>4.513</b>	4.390	4.330	4.520	<b>4.413</b>	<b>4.518</b>	
<b>Mean</b>	<b>3.99</b>	<b>4.01</b>	<b>4.49</b>	<b>4.166</b>	<b>4.03</b>	<b>3.98</b>	<b>4.22</b>	<b>4.079</b>	<b>3.90</b>	<b>3.95</b>	<b>4.11</b>	<b>3.992</b>		

SSL: (sodium stearyl-2-lactylate),GG: (guar gum) and CMC:(carboxymethyl cellulose)

<b>C.D (P&lt;0.05) Days</b>	=	0.018
Hydrocolloid	=	0.014
Days × Hydrocolloid	=	0.031
Concentration	=	0.014
Days × concentration	=	0.031
Hydr × Concentration	=	0.024
Days × Hydr × Conc	=	0.054.

**Table 4.46: Effect of hydrocolloids, storage days on yellowness (*b\** value) of low- gluten flat bread**

Storage Period (Days)	0.3%.				0.6%				0.9%				Mean	Factor
	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub mean		
0	23.75	24.48	24.40	<b>24.21</b>	23.15	24.44	24.01	<b>23.86</b>	23.05	23.98	23.38	<b>23.47</b>	<b>23.84</b>	<b>SSL=25.29</b> <b>GG=24.67</b> <b>CMC=24.32</b>
2	23.73	24.43	24.38	<b>23.84</b>	23.10	23.96	23.88	<b>23.64</b>	22.97	23.91	23.32	<b>23.4</b>	<b>23.62</b>	
4	23.66	24.36	24.31	<b>24.20</b>	23.03	23.89	23.81	<b>23.57</b>	22.95	22.84	23.25	<b>23.01</b>	<b>23.63</b>	
6	23.20	23.13	23.28	<b>23.20</b>	22.59	22.78	22.89	<b>22.75</b>	21.82	22.45	21.65	<b>21.9</b>	<b>22.61</b>	
8	22.40	22.43	21.58	<b>22.13</b>	21.35	21.68	21.45	<b>21.49</b>	20.43	21.35	20.95	<b>20.91</b>	<b>21.51</b>	
Mean	<b>23.34</b>	<b>23.76</b>	<b>23.59</b>	<b>23.51</b>	<b>22.64</b>	<b>23.35</b>	<b>23.20</b>	<b>23.06</b>	<b>22.24</b>	<b>22.90</b>	<b>22.51</b>	<b>22.53</b>	<b>23.03</b>	

SSL: (sodium stearyl-2-lactylate),GG: (guar gum) and CMC:(carboxymethyl cellulose)

<b>CD (P&lt;0.05)</b> Days	=	0.025
Hydrocolloid	=	0.019
Days × Hydrocolloid	=	0.043
Concentration	=	0.019
Days × concentration	=	0.043
Hydr× Concentration	=	0.033
DaysxHydr × Conc	=	0.075

### **4.3.3 Bread Parameters**

#### **4.3.3.1 Spread ratio**

Analysis of data for spread ratio of low gluten optimized flat breads incorporated with different hydrocolloids (Sodium stearoyl-2 lactylate-SSL, Guar gum-GG and carboxymethyl cellulose-CMC) at (0.3%, 0.6% and 0.9%) concentrations during storage for 8 days is depicted in Table 4.47. Data analysis indicated that, with increase in concentration of hydrocolloids from 0.3 to 0.9%, spread ratio decreased in SSL, GG and CMC incorporated flat breads. However less decrease in spread ratio was noticed in CMC incorporated low gluten flat bread from (15.40 to 15.10) at 0.9% concentration followed by SSL flat bread from (15.45 to 15.00) and GG flat bread from (15.30 to 14.50). Furthermore, it was observed that spread ratio decreases with increase in storage period and the values ranged from (15.10 to 14.70) in CMC flat bread (15.00 to 14.70) in SSL flat bread and (14.50 to 13.90) in GG flat bread from 0 to 8<sup>th</sup> day of storage.

#### **4.3.3.2 Width**

Table 4.48 depicts the data regarding the effect of different hydrocolloids (Sodium stearoyl lactylate-SSL, Guar gum-GG and carboxymethyl cellulose-CMC), hydrocolloids concentration (0.3%, 0.6% and 0.9%) and storage days on optimized low -gluten flat bread. Analysis revealed that width of optimized flat bread decreased with increase in hydrocolloids incorporation from (126.52 to 123.96mm) in SSL incorporated fat bread (128.12 to 124.02mm) in GG incorporated flat bread and (125.5 to 122.16mm) in CMC incorporated flat bread at 0.3, 0.6 and 0.9% concentrations, respectively. Furthermore, with increase in storage period from 0 to 8<sup>th</sup> day width in flat breads was found to be decreased, however more decrease was observed in CMC incorporated flat bread from (122.16 to 122.13mm) and less increase was noticed in GG incorporated flat bread from (124.02 to 126.01) at 0.9% concentration .

**Table 4.47: Effect of hydrocolloids, storage days on Spread ratio of low-gluten flat bread**

Storage Period (Days)	0.3%				0.6%				0.9%				Mean	Factor
	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub mean		
0	15.45	15.30	15.40	<b>15.38</b>	15.30	14.70	15.20	<b>15.06</b>	15.00	14.50	15.10	<b>14.86</b>	<b>15.10</b>	<b>SSL=15.13</b> <b>GG=14.54</b> <b>CMC=15.07</b>
2	15.44	15.30	15.30	<b>15.34</b>	15.20	14.50	15.20	<b>14.96</b>	15.00	14.20	15.00	<b>14.73</b>	<b>15.01</b>	
4	15.43	15.20	15.20	<b>15.27</b>	15.10	14.20	15.10	<b>14.80</b>	14.90	14.10	14.90	<b>14.63</b>	<b>14.90</b>	
6	15.42	15.10	15.10	<b>15.20</b>	15.00	14.10	15.10	<b>14.73</b>	14.80	14.00	14.80	<b>14.53</b>	<b>14.82</b>	
8	15.41	15.00	15.00	<b>15.13</b>	14.90	14.00	15.00	<b>14.63</b>	14.70	13.90	14.70	<b>14.43</b>	<b>14.73</b>	
Mean	<b>15.43</b>	<b>15.18</b>	<b>15.20</b>	<b>15.27</b>	<b>15.10</b>	<b>14.30</b>	<b>14.12</b>	<b>14.84</b>	<b>14.88</b>	<b>14.14</b>	<b>14.90</b>	<b>14.64</b>		

SSL: (sodium stearyl-2-lactylate),GG: (guar gum) and CMC:(carboxymethyl cellulose)

- C.D(p<0.05)** Days = 0.051
- Hydrocolloid = 0.040
- Days × Hydrocolloid = 0.088
- Concentration = 0.040
- Days × concentration = 0.09
- Hydr × Concentration = 0.068
- Days × Hydr × Conc = 0.0153.

**Table 4.48: Effect of hydrocolloids, storage days on width of low- gluten flat bread**

Storage Period (Days)	0.3%				0.6%				0.9%				Mean	Factor
	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub Mean	SSL	GG	CMC	Sub mean		
0	126.52	128.12	125.55	<b>126.73</b>	125.47	126.05	124.32	<b>125.28</b>	123.96	124.02	122.16	<b>123.38</b>	<b>125.13</b>	SSL=125.368 GG=127.216 CMC=124.021
2	126.52	128.12	125.55	<b>126.73</b>	125.47	127.05	124.32	<b>125.28</b>	123.95	125.02	122.15	<b>123.37</b>	<b>125.12</b>	
4	126.51	128.11	125.54	<b>126.72</b>	125.46	129.04	124.31	<b>126.27</b>	123.95	126.02	122.15	<b>124.37</b>	<b>125.78</b>	
6	126.51	128.11	125.54	<b>126.72</b>	125.46	129.03	124.30	<b>126.26</b>	124.92	126.01	122.14	<b>124.35</b>	<b>125.77</b>	
8	126.50	128.10	125.53	<b>126.71</b>	125.45	129.03	124.30	<b>126.25</b>	124.91	126.01	122.13	<b>124.35</b>	<b>125.77</b>	
Mean	<b>126.51</b>	<b>128.11</b>	<b>125.54</b>	<b>126.72</b>	<b>125.46</b>	<b>128.02</b>	<b>124.31</b>	<b>125.26</b>	<b>123.93</b>	<b>125.01</b>	<b>122.14</b>	<b>123.36</b>		

SSL: (sodium stearyl-2-lactylate),GG: (guar gum) and CMC:(carboxymethyl cellulose)

**C.D(p<0.05)** Days = Ns;  
 Hydrocolloid = 0.418  
 Concentration = Ns;  
 Days × Hydrocolloid = Ns  
 Days × concentration = Ns  
 Hydr × Concentration = Ns  
 Days× Hydr×conc = Ns.

#### **4.3.3.3 Thickness**

Analysis of data for thickness of optimized low-gluten flat breads incorporated with different hydrocolloids (Sodium stearoyl-2 lactylate-SSL, Guar gum-GG and carboxymethyl cellulose-CMC) at (0.3%, 0.6% and 0.9%) concentrations during storage period for 8 days are depicted in Table 4.49. Data analysis indicate that, with increase in concentration of hydrocolloids from 0.3 to 0.9%, increased in thickness was noticed in SSL, GG and CMC incorporated optimized low gluten flat breads. However higher thickness was found in CMC incorporated flat bread at 0.9% concentration (9.75mm) at 0 day of storage. while as lower thickness was observed in SSL incorporated flat bread (9.05mm) at same concentration. Further more, it was observed that thickness decreases from 0 to 8 days of storage, Whereas, more decrease was noticed in SSL incorporated flat bread from (9.05 to 9.03 mm) and less decrease was noticed in CMC incorporated flat bread (9.75 to 9.73mm).

#### **4.3.3.4 Volume index**

Table 4.50 depicts the analysis of data for volume index of optimized low - gluten flat breads incorporated with different hydrocolloids (Sodium stearoyl-2 lactylate-SSL, Guar gum-GG and carboxymethyl cellulose-CMC) at (0.3%, 0.6% and 0.9%) concentrations during storage period for 8 days. Data analysis indicate that, with increase in hydrocolloid incorporation from 0.3 to 0.9% concentration, volume index increased significantly ( $p < 0.05$ ). However, more increase was observed from (1.55 to 1.62 cm) in CMC incorporated flat, followed by (1.53 to 1.60cm) in GG flat bread and (1.54 to 1.61cm) in SSL incorporated flat bread. In addition volume index decreased during the entire storage period of 8 days. More decrease in volume index was noticed in GG bread from (1.60 to 1.56 cm), whereas, less decrease was noticed in CMC flat bread from (1.62 to 1.59 cm) during the storage period from 0 to 8<sup>th</sup>.

**Table 4.49: Effect of hydrocolloids, storage days on thickness of low -gluten flat bread**

Storage Period (Days)	0.3%				0.6%				0.9%				Mean	Factor
	SSL	GG	CMC	Sub Mean	SSL	GG	CMC	Sub Mean	SSL	GG	CMC	Sub mean		
0	8.48	8.54	8.92	<b>8.64</b>	8.87	8.79	9.51	<b>9.05</b>	9.05	9.15	9.75	<b>9.31</b>	<b>8.94</b>	SSL= 8.85 GG= 8.80 CMC=9.44
2	8.48	8.54	8.92	<b>8.64</b>	8.87	8.79	9.51	<b>9.05</b>	9.05	9.15	9.75	<b>9.31</b>	<b>8.94</b>	
4	8.47	8.53	8.91	<b>8.63</b>	8.86	8.78	9.50	<b>9.04</b>	9.04	9.14	9.74	<b>9.30</b>	<b>8.99</b>	
6	8.47	8.53	8.91	<b>8.63</b>	8.85	8.78	9.50	<b>9.04</b>	9.04	9.13	9.73	<b>9.30</b>	<b>8.99</b>	
8	8.46	8.52	8.90	<b>8.62</b>	8.85	8.77	9.49	<b>9.03</b>	9.03	9.13	9.73	<b>9.29</b>	<b>8.98</b>	
Mean	<b>8.47</b>	<b>8.53</b>	<b>8.91</b>	<b>8.63</b>	<b>8.86</b>	<b>8.78</b>	<b>9.50</b>	<b>9.04</b>	<b>9.04</b>	<b>9.14</b>	<b>9.74</b>	<b>9.30</b>		

SSL: (sodium stearyl-2-lactylate),GG: (guar gum) and CMC:(carboxymethyl cellulose)

<b>C.D(p&lt;0.05)</b> Days	=	0.017
Hydrocolloid	=	0.013
Days × Hydrocolloid	=	0.03
Concentration	=	0.013
Days × concentration	=	0.03
Hydr × Concentration	=	0.023
Days × Hydr × Conc	=	0.04

**Table 4.50: Effect of hydrocolloids, storage days on volume index of low- gluten flat bread**

Storage Period (Days)	0.3%				0.6%				0.9%				Mean	Factor
	SSL	GG	CMC	Sub Mean	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub mean		
0	1.54	1.53	1.55	<b>1.54</b>	1.57	1.58	1.59	<b>1.58</b>	1.61	1.60	1.62	<b>1.61</b>	<b>1.57</b>	SSL=1.55 GG=1.55 CMC=1.57
2	1.53	1.52	1.54	<b>1.53</b>	1.56	1.57	1.58	<b>1.57</b>	1.60	1.59	1.62	<b>1.60</b>	<b>1.56</b>	
4	1.52	1.51	1.53	<b>1.52</b>	1.55	1.56	1.57	<b>1.56</b>	1.59	1.68	1.61	<b>1.59</b>	<b>1.55</b>	
6	1.51	1.50	1.52	<b>1.51</b>	1.54	1.55	1.56	<b>1.55</b>	1.58	1.57	1.60	<b>1.58</b>	<b>1.54</b>	
8	1.50	1.49	1.51	<b>1.50</b>	1.52	1.54	1.55	<b>1.53</b>	1.57	1.56	1.59	<b>1.57</b>	<b>1.53</b>	
<b>Mean</b>	<b>1.52</b>	<b>1.51</b>	<b>1.53</b>	<b>1.52</b>	<b>1.54</b>	<b>1.56</b>	<b>1.57</b>	<b>1.56</b>	<b>1.59</b>	<b>1.58</b>	<b>1.60</b>	<b>1.59</b>		

SSL: (sodium stearyl-2-lactylate),GG: (guar gum) and CMC:(carboxymethyl cellulose)

**C.D(p<0.05)** Days = 0.006  
 Hydrocolloid = NS  
 Days × Hydrocolloid = NS  
 Concentration = NS  
 Days × concentration = 0.01  
 Hydr × Concentration = NS  
 Days × Hydr × Conc = NS

#### 4.3.3.5 Weight

Analysis of data for weight of low gluten optimized flat breads incorporated with different hydrocolloids (Sodium stearyl-2 lactylate-SSL, Guargum-GG and carboxymethyl cellulose-CMC) at (0.3%, 0.6% and 0.9%) concentrations during storage for 8 days is depicted in Table (4.51). Data analysis indicated that, with increase in concentration of hydrocolloids from 0.3 to 0.9%, weight was increased in SSL, GG and CMC incorporated low-gluten flat breads. However maximum increase was noticed in CMC incorporated flat bread from (66.15 to 70.25g) at 0.9% concentration followed by GG flat bread from (65.25 to 67.51 g) and SSL flat bread from (63.42 to 65.75 g). Furthermore, it was observed that weight of low gluten flat breads decreases with increase in storage period and the values ranged from (70.25 to 70.20 g) in CMC flat bread (67.51 to 65.55g) in GG flat bread and (65.75 to 65.11g) in GG flat bread respectively from 0 to 8<sup>th</sup> day of storage.

#### 4.3.3.6 Specific volume

The data regarding the effect of different hydrocolloids (Sodium stearyl lactylate-SSL, Guargum-GG and carboxymethyl cellulose-CMC), hydrocolloids concentration (0.3%, 0.6% and 0.9%) and storage days on specific volume of optimized low-gluten flat bread is illustrated in Table (4.52). Analysis of data revealed that, with increase in concentration of hydrocolloids from 0.3 to 0.9%, of specific volume was increased in SSL, GG and CMC incorporated optimized low-gluten flat breads. However higher specific volume was found in CMC incorporated flat bread at 0.9% concentration (4.47 cm<sup>3</sup>/g) at 0 day of storage. while as lower specific volume was observed in SSL incorporated flat bread (4.17 cm<sup>3</sup>/g) at similar concentration. Moreover, it was observed that with increase in storage period from 0 to 8 days, decrease in specific volume was noticed. whereas as, higher decrease was found in SSL incorporated flat bread from (4.17 to 4.13 cm<sup>3</sup>/g) and lesser decline was noticed in CMC incorporated flat bread from (4.47 to 4.43 cm<sup>3</sup>/g) respectively.

**Table 4.51: Effect of hydrocolloids, storage days on weight of low-gluten flat bread**

Storage Period (Days)	0.3%				0.6%				0.9%				Mean	Factor
	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub Mean	SSL	GG	CMC	Sub mean		
0	63.42	65.25	66.15	<b>64.94</b>	64.48	65.59	69.13	<b>66.40</b>	65.75	67.51	70.25	<b>67.83</b>	66.39	SSL=64.53 GG=65.62 CMC=68.55
2	63.41	65.24	67.13	<b>65.26</b>	64.47	65.58	69.12	<b>66.39</b>	65.74	67.50	70.24	<b>67.82</b>	66.49	
4	63.40	65.12	66.13	<b>64.88</b>	64.46	65.22	69.11	<b>66.26</b>	65.73	65.57	70.22	<b>67.17</b>	66.10	
6	63.39	65.11	66.12	<b>64.87</b>	64.45	65.21	69.10	<b>66.25</b>	65.72	65.56	70.21	<b>67.16</b>	66.09	
8	63.38	65.10	66.11	<b>64.86</b>	64.44	65.20	69.09	<b>66.24</b>	65.11	65.55	70.20	<b>67.15</b>	66.08	
Mean	<b>63.40</b>	<b>65.16</b>	<b>66.32</b>	<b>64.96</b>	<b>65.46</b>	<b>65.36</b>	<b>69.11</b>	<b>66.31</b>	<b>65.73</b>	<b>66.33</b>	<b>70.22</b>	<b>67.43</b>		

SSL: (sodium stearyl-2-lactylate),GG: (guar gum) and CMC:(carboxymethyl cellulose)

<b>C.D(p&lt;0.05)</b> Days	=	0.138
Hydrocolloid	=	0.107
Concentration	=	0.107
Days × Hydrocolloid	=	0.239
Days × concentration	=	0.239
Hydr× Concentration	=	0.185
Days × Hyd × Conc	=	0.413.

**Table 4.52: Effect of hydrocolloids, storage days on specific volume of low-gluten flat bread**

Storage Period (Days)	0.3%				0.6%				0.9%				Mean	Factor
	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub Mean	SSL	GG	CMC	Sub mean		
0	3.97	3.84	4.04	<b>3.95</b>	4.01	4.03	4.38	<b>4.14</b>	4.17	4.25	4.47	<b>4.29</b>	<b>4.12</b>	SSL=4.03 GG=4.01 CMC=.27
2	3.96	3.83	4.04	<b>3.94</b>	4.03	4.05	4.38	<b>4.15</b>	4.16	4.24	4.46	<b>4.28</b>	<b>4.12</b>	
4	3.95	3.82	4.03	<b>3.93</b>	3.99	4.01	4.36	<b>4.12</b>	4.15	4.22	4.45	<b>4.27</b>	<b>4.10</b>	
6	3.94	3.81	4.01	<b>3.92</b>	3.98	3.99	4.35	<b>4.10</b>	4.14	4.21	4.44	<b>4.26</b>	<b>4.09</b>	
8	3.93	3.80	4.00	<b>3.91</b>	3.97	3.97	4.34	<b>4.09</b>	4.13	4.20	4.43	<b>4.25</b>	<b>4.08</b>	
<b>Mean</b>	<b>3.95</b>	<b>3.82</b>	<b>4.02</b>	<b>3.931</b>	<b>3.99</b>	<b>4.01</b>	<b>4.36</b>	<b>4.123</b>	<b>4.15</b>	<b>4.22</b>	<b>4.45</b>	<b>4.275</b>		

SSL: (sodium stearyl-2-lactylate),GG: (guar gum) and CMC:(carboxymethyl cellulose)

<b>C.D(p&lt;0.05)</b> Days	=	0.016
Hydrocolloid	=	0.012
Days × Hydrocolloid	=	0.028
Concentration	=	0.012
Days × concentration	=	0.028
Hydr × Concentration	=	0.024
Days × Hydr × conc	=	0.04

#### **4.3.3.7 Puffiness**

The data for puffiness of low gluten optimized flat breads incorporated with different hydrocolloids (Sodium stearoyl-2 lactylate-SSL, Guargum-GG and carboxymethyl cellulose-CMC) at (0.3%, 0.6% and 0.9%) concentrations during storage for 8 days is depicted in Table (4.53). Data analysis specify that puffiness % was decreased with increase in hydrocolloid concentration from 0.3 to 0.9%. Analysis further revealed that maximum puffiness was recorded in CMC incorporated flat bread (25.76%) at 0.9% concentration. while as minimum puffiness was noticed in SSL incorporated flat bread (21.61%) respectively. Further it was observed that with increase in storage period from 0 to 8<sup>th</sup> day, puffiness% was found to be decreased. Higher decrease in puffiness was noticed in SSL flat bread from (21.61 to 20.48%) and lower decline in puffiness was found in CMC flat bread from (25.76 to 24.33%) for 0.9% concentration.

#### **4.3.3.8 Oven spring**

Analysis of data for oven spring of low-gluten optimized flat breads incorporated with different hydrocolloids (Sodium stearoyl-2 lactylate-SSL, Guargum-GG and carboxymethyl cellulose-CMC) at (0.3%, 0.6% and 0.9%) concentrations during storage for 8 days is depicted in Table (4.54). Data analysis indicated that, with increase in concentration of hydrocolloids from 0.3 to 0.9%, oven spring was increased in SSL, GG and CMC incorporated low-gluten flat breads. However maximum increase was noticed in CMC incorporated flat bread from (1.59 to 1.73 cm) at 0.9% concentration followed by GG flat bread from (1.53 to 1.63 cm) and SSL flat bread from (1.51 to 1.57 cm). Furthermore, it was observed that oven spring of low gluten flat breads decreases with increase in storage period. and the values ranged from (1.73 to 1.69 cm) in CMC flat bread (1.63 to 1.59 cm) in GG flat bread and (1.57 to 1.53 cm) in SSL flat bread respectively from 0 to 8<sup>th</sup> day of storage.

**Table 4.53: Effect of hydrocolloids, storage days on puffiness of low-gluten flat bread**

Storage Period (Days)	0.3%				0.6%				0.9%				Mean	Factor
	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub Mean	SSL	GG	CMC	Sub mean		
0	22.90	23.98	26.13	<b>24.33</b>	21.66	22.28	25.80	<b>23.24</b>	21.61	22.24	25.76	<b>21.85</b>	<b>23.14</b>	SSL=21.717 GG=25.415 CMC=22.240
2	22.90	23.97	26.12	<b>24.33</b>	21.64	22.27	25.79	<b>23.23</b>	20.51	20.64	24.36	<b>21.83</b>	<b>23.13</b>	
4	22.89	23.96	26.12	<b>24.32</b>	21.63	22.26	25.78	<b>23.22</b>	20.50	20.63	24.35	<b>21.82</b>	<b>23.12</b>	
6	22.88	23.95	26.11	<b>24.31</b>	21.62	22.25	25.77	<b>23.21</b>	20.49	20.62	24.34	<b>21.81</b>	<b>23.11</b>	
8	22.87	23.94	26.10	<b>24.30</b>	21.61	22.24	25.76	<b>23.20</b>	20.48	20.61	24.33	<b>21.80</b>	<b>23.10</b>	
<b>Mean</b>	<b>22.88</b>	<b>23.96</b>	<b>26.11</b>	<b>24.32</b>	<b>21.63</b>	<b>22.26</b>	<b>25.78</b>	<b>23.22</b>	<b>20.50</b>	<b>20.63</b>	<b>24.35</b>	<b>21.82</b>		

SSL: (sodium stearyl-2-lactylate),GG: (guar gum) and CMC:(carboxymethyl cellulose)

- C.D(p<0.05)** Days = 0.027
- Hydrocolloid = 0.021
- Concentration = 0.048
- Days × Hydrocolloid = 0.021
- Days × concentration = 0.048
- Hydrocolloid × Concentration = 0.042
- Days× Hydr × conc = 0.069

**Table 4.54: Effect of hydrocolloids, storage days on oven spring of low- gluten flat bread**

Storage Period (Days)	0.3%				0.6%				0.9%				Mean	Factor
	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub Mean	SSL	GG	CMC	Sub mean		
0	1.51	1.53	1.59	1.54	1.55	1.58	1.65	<b>1.59</b>	1.57	1.63	1.73	<b>1.64</b>	<b>1.59</b>	SSL=1.526 GG=1.562 CMC=1.639
2	1.50	1.52	1.59	1.53	1.54	1.57	1.64	<b>1.58</b>	1.56	1.62	1.72	<b>1.63</b>	<b>1.58</b>	
4	1.50	1.51	1.58	1.53	1.53	1.56	1.63	<b>1.57</b>	1.55	1.62	1.71	<b>1.62</b>	<b>1.57</b>	
6	1.49	1.50	1.57	1.52	1.52	1.55	1.62	<b>1.56</b>	1.54	1.61	1.70	<b>1.61</b>	<b>1.56</b>	
8	1.48	1.49	1.56	1.51	1.51	1.54	1.61	<b>1.55</b>	1.53	1.59	1.69	<b>1.60</b>	<b>1.55</b>	
<b>Mean</b>	<b>1.49</b>	<b>1.51</b>	<b>1.57</b>	<b>1.528</b>	<b>1.53</b>	<b>1.56</b>	<b>1.63</b>	<b>1.57</b>	<b>1.55</b>	<b>1.61</b>	<b>1.71</b>	<b>1.625</b>		

SSL: (sodium stearyl-2-lactylate),GG: (guar gum) and CMC:(carboxymethyl cellulose)

<b>C.D (p&lt;0.05) Days</b>	=	0.005
Hydrocolloid	=	0.004
Concentration	=	0.004
Days × Hydrocolloid	=	0.009
Days × concentration	=	0.009
Hydrocolloid × Concentration	=	0.008
Days×Hydr × conc	=	0.066

#### 4.3.3.9 Yield

The data with regard to yield % of low gluten optimized flat breads incorporated with different hydrocolloids (Sodium stearoyl-2 lactylate-SSL, Guargum-GG and carboxymethyl cellulose-CMC) at (0.3%, 0.6% and 0.9%) concentrations during storage for 8 days is depicted in Table (4.55). Data analysis indicated that, with increase in concentration of hydrocolloids from 0.3 to 0.9%, yield % was increased in SSL, GG and CMC incorporated low -gluten flat breads. Concentration wise, the yield increased from (135.8 to 139.22%) in CMC incorporated flat bread (131.98 to 136.82%) in GG flat bread and from (130.81 to 135.77%) in SSL flat bread in that order respectively. However, with increase in storage period yield showed a decreasing trend. Higher decrease in yield was noticed in SSL flat bread from (135.77 to 135.74%), while as lower decrease in yield % was observed in CMC flat bread from (139.22 to 139.19).

#### 4.3.3.10 Degree of staling using FT-IR spectroscopy

FT-IR spectrum of starch is reported to be sensitive to changes in structure at a molecular level (short-range order), such as starch chain conformation, crystallinity and retrogradation (Bian and Chung, 2016). FT-IR spectra of low gluten optimized flat breads incorporated with different hydrocolloids (Sodium stearoyl-2 lactylate-SSL, Guargum-GG and carboxymethyl cellulose-CMC) at (0.3%, 0.6% and 0.9%) concentrations during storage for 8 days are presented in figures from (Fig 4.21 a,b,c). FT-IR spectra at 1047 and 1151  $\text{cm}^{-1}$  are known to be sensitive to changes in the crystalline and amorphous regions, respectively near the granular surface of starch (Chung *et al.*, 2009a). The ratio of peak intensities at 1,047 and 1,151  $\text{cm}^{-1}$ , which was assigned in literature (Ottenhof *et al* 2005) was used to monitor starch retrogradation. with bending of C–O–H bonds . The ratio of spectra at 1047/1151 of guar gum incorporated low gluten flat breads was significantly ( $p \leq 0.05$ ) lower than SSL and CMC incorporated flat breads (Fig. 4.21,b).

As depicted in in Table 4.56 with increase in storage days there was an increase in absorption ratios at 1047 and 1151  $\text{cm}^{-1}$ , however higher increase in absorption ratios was observed in SSL incorporated low gluten breads and less increase in absorption ratios was observed in guar gum incorporated low gluten flat breads indicating less staling.

**Table 4.55: Effect of hydrocolloids, storage days on yield of low gluten flat bread**

Storage Period (Days)	0.3%				0.6%				0.9%				Mean	Factor
	SSL	GG	CMC	Sub Mean	SSL	GG	CMC	Sub Mean	SSL	GG	CMC	Sub mean		
0	130.81	131.98	135.82	<b>132.87</b>	132.37	133.77	137.61	<b>134.58</b>	135.77	136.82	139.22	<b>137.27</b>	<b>134.90</b>	SSI=132.90 GG=134.17 CMC=139.52
2	130.80	131.98	135.81	<b>132.86</b>	132.36	133.76	137.59	<b>134.57</b>	135.76	136.81	139.21	<b>137.26</b>	<b>134.89</b>	
4	130.79	131.96	135.80	<b>132.85</b>	131.35	133.75	137.58	<b>134.22</b>	135.75	136.80	139.20	<b>137.25</b>	<b>134.88</b>	
6	130.79	131.95	135.79	<b>132.84</b>	132.35	133.74	137.57	<b>134.55</b>	135.75	136.79	139.20	<b>137.24</b>	<b>134.88</b>	
8	130.78	131.94	135.78	<b>132.83</b>	132.34	133.73	137.56	<b>134.54</b>	135.74	136.78	139.19	<b>137.23</b>	<b>134.87</b>	
<b>Mean</b>	<b>130.79</b>	<b>131.96</b>	<b>135.80</b>	<b>132.85</b>	<b>132.15</b>	<b>133.75</b>	<b>137.58</b>	<b>134.49</b>	<b>135.75</b>	<b>136.80</b>	<b>139.20</b>	<b>137.25</b>		

SSL: (sodium stearyl-2-lactylate),GG: (guar gum) and CMC:(carboxymethyl cellulose)

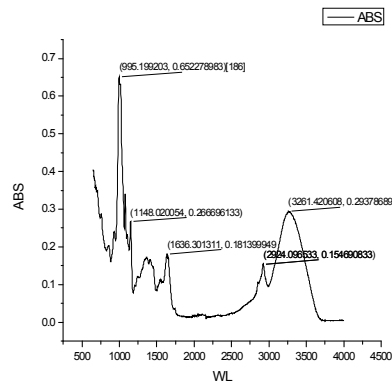
- C.D (p<0.05) Days = 0.022
- Hydrocolloid = 0.017
- Concentration = 0.017
- Days × Hydrocolloid = 0.038
- Days × concentration = 0.038
- Hydrocolloid × Concentration = 0.030
- Days ×Hydr × conc = 0.066

**Table 4.56: Validation of FT-IR with absorbance ratios at peak 1047 and 1151 cm<sup>-1</sup>**

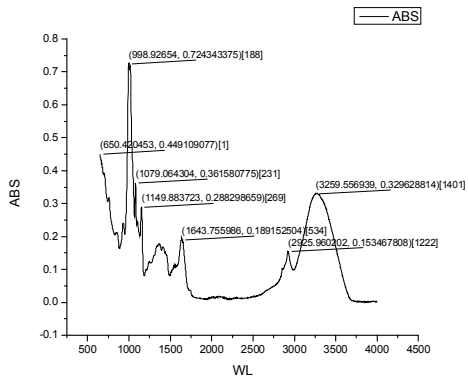
Storage Period (Days)	0.3%				0.6%				0.9%				Mean	Factor
	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub Mean	SSL	GG	CMC	Sub mean		
0	1.370	1.354	1.330	<b>1.371</b>	1.357	1.311	1.395	<b>1.348</b>	1.387	1.359	1.379	<b>1.375</b>	<b>1.365</b>	SSL=1.386 GG=1.349 CMC=1.375
2	1.397	1.360	1.330	<b>1.352</b>	1.377	1.311	1.375	<b>1.364</b>	1.381	1.366	1.385	<b>1.377</b>	<b>1.365</b>	
4	1.408	1.371	1.343	<b>1.367</b>	1.403	1.308	1.369	<b>1.363</b>	1.392	1.368	1.395	<b>1.352</b>	<b>1.361</b>	
6	1.422	1.387	1.363	<b>1.372</b>	1.403	1.301	1.358	<b>1.364</b>	1.393	1.394	1.396	<b>1.394</b>	<b>1.377</b>	
8	1.447	1.381	1.417	<b>1.404</b>	1.411	1.276	1.346	<b>1.358</b>	1.402	1.364	1.403	<b>1.390</b>	<b>1.384</b>	
Mean	<b>1.387</b>	<b>1.371</b>	<b>1.363</b>	<b>1.373</b>	<b>1.386</b>	<b>1.307</b>	<b>1.385</b>	<b>1.359</b>	<b>1.385</b>	<b>1.370</b>	<b>1.377</b>	<b>1.377</b>		

SSL: (sodium stearyl-2-lactylate), GG: (guar gum) and CMC:(carboxymethyl cellulose)

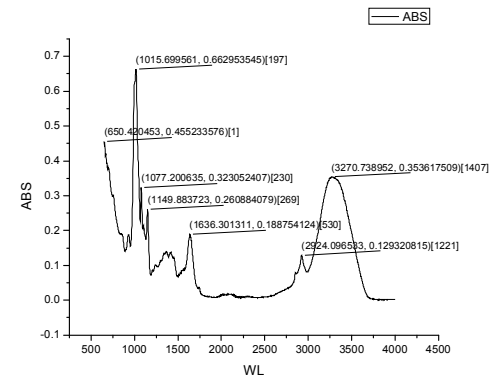
<b>C.D (P≤0.05) Days</b>	=	0.008
Hydrocolloid	=	0.006
Days × Hydrocolloid	=	0.013
Concentration	=	0.006
Days × concentration	=	0.013
Hydr × Concentration	=	0.010
Days × Hydr × conc	=	0.023.



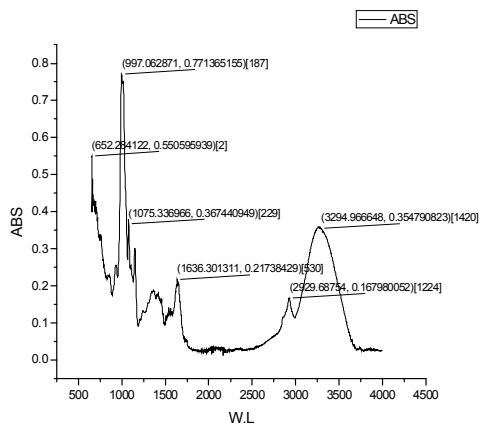
**0.3%SSL 0 day**



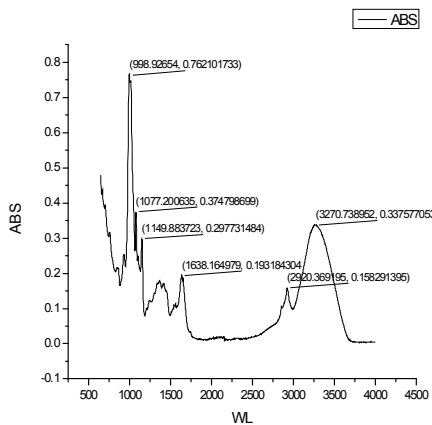
**0.6%SSL 0 day**



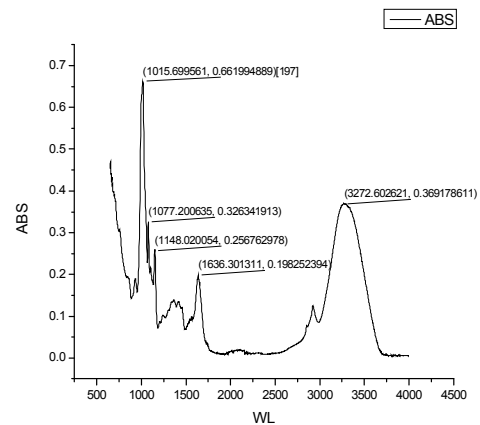
**0.9%SSL 0 day**



**0.3%SSL 8<sup>th</sup> day**



**0.6%SSL 8<sup>th</sup> day**



**0.9%SSL 8<sup>th</sup> day**

**Fig. 4.21(a): Degree of staling in SSL incorporated flat breads using FTIR**

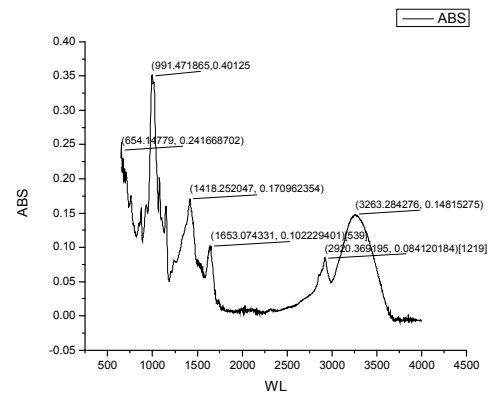
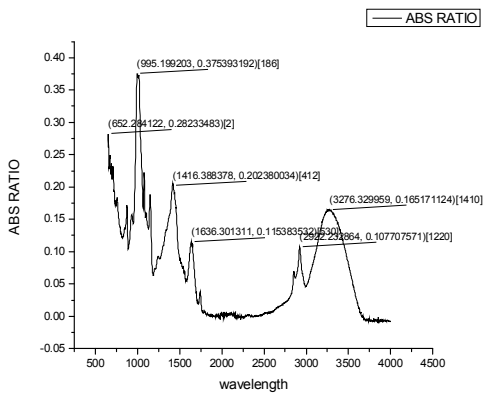
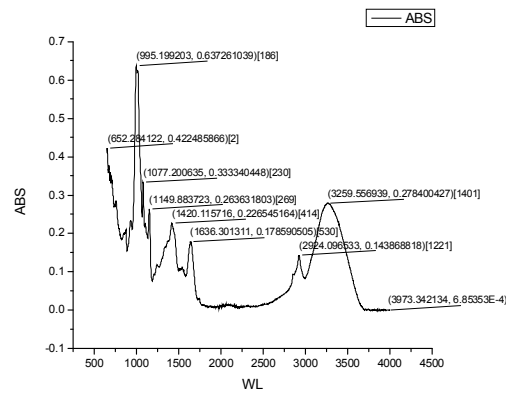
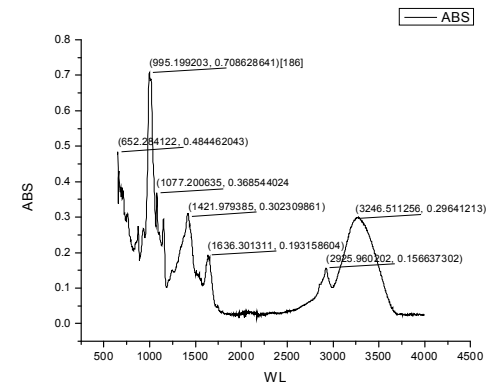
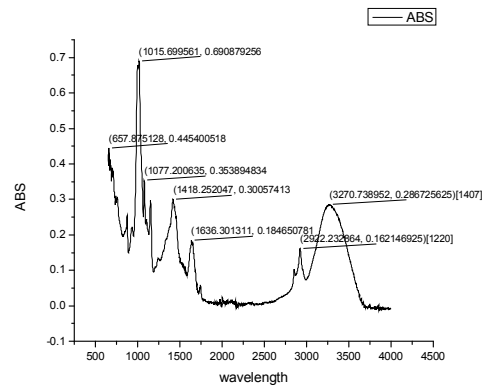
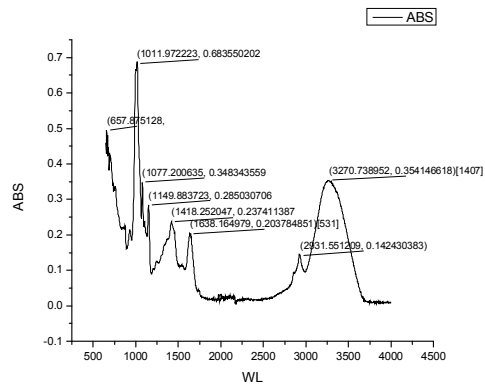
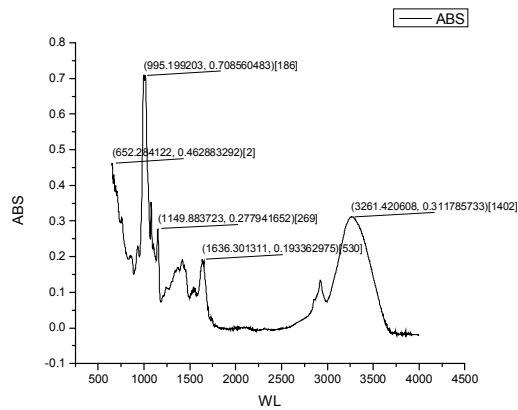
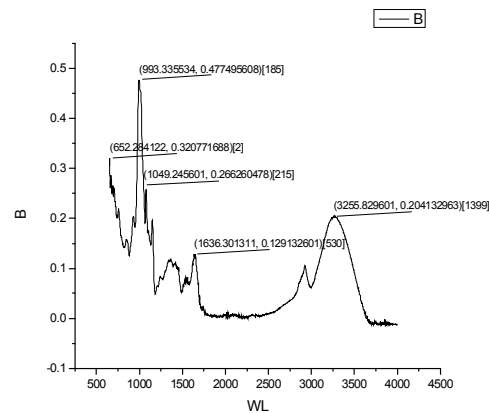


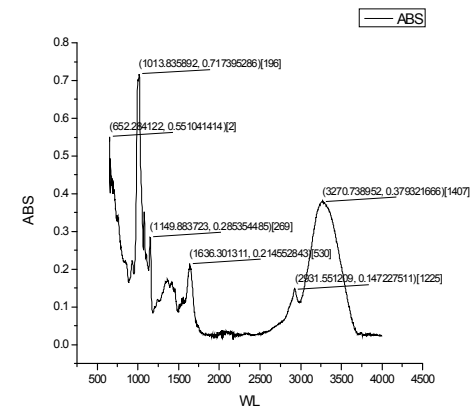
Fig. 4.21(b): Degree of staling in guar gum incorporated flat breads using FTIR



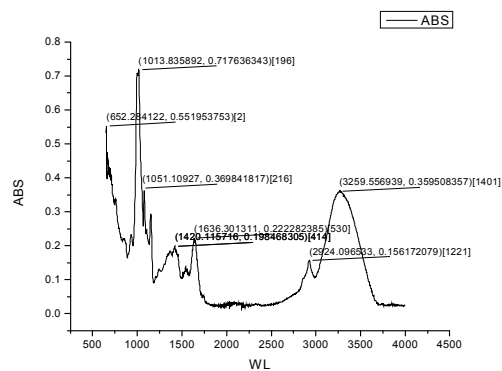
**0.3% CMC 0 day**



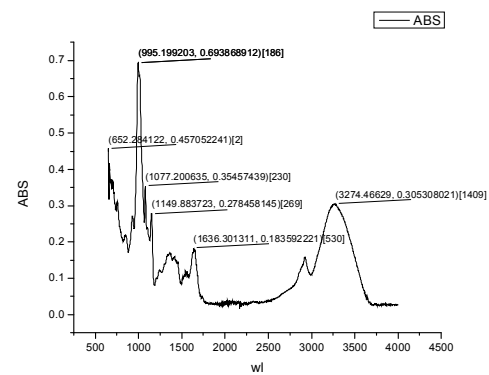
**0.6% CMC 0 day**



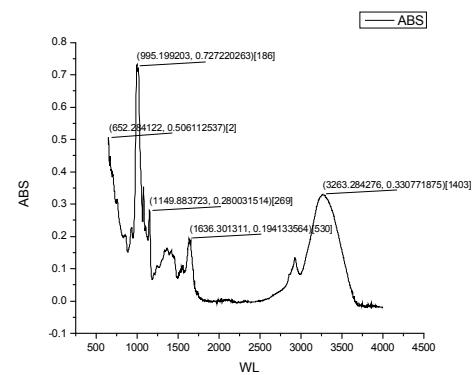
**0.9% CMC 0 day**



**0.3% CMC 8<sup>th</sup> day**



**0.6% CMC 8<sup>th</sup> day**



**0.9% CMC 8<sup>th</sup> day**

**Fig. 4.21(c): Degree of staling in CMC incorporated flat breads using FTIR.**

#### **4.3.4 Sensory evaluation**

##### **4.3.4.1 Appearance**

Table 4.57 to 4.61 shows the organoleptic evaluation scores of optimized low-gluten flat breads incorporated with different hydrocolloids (Sodium stearoyl-2 lactylate-SSL, Guargum-GG and carboxymethyl cellulose-CMC) at (0.3%, 0.6% and 0.9%) concentrations during storage for 8 days. Analysis of data from Table 4.57 indicated that hydrocolloid incorporation, concentration and storage period had a significant influence on various organoleptic attributes of optimized low-gluten flat breads. With increase in hydrocolloid concentration the score for appearance increased significantly at 0.6% concentration, the respective mean score was noticed to increase from (4.0 to 4.6) for GG flat bread (3.98 to 4.5) for CMC flat bread (3.90 to 4.30) for SSL flat bread. However with increase in storage period, the scores for appearance decreased significantly from 0 to 8<sup>th</sup> day of storage. The scores for appearance in GG flat bread decreased from (4.80 to 4.40) (4.70 to 4.30) in CMC flat bread and from (4.60 to 4.10) in SSL flat bread .

##### **4.3.4.2 Colour**

The data recorded pertaining to the organoleptic attributes of optimized low gluten flat breads based on 5 point hedonic scale, incorporated with different hydrocolloids (Sodium stearoyl-2 lactylate-SSL, Guargum-GG and carboxymethyl cellulose-CMC) at (0.3%, 0.6% and 0.9%) concentrations during storage for 8 days are presented in Table 4.58. Analysis of data revealed that colour scores increased with the addition of hydrocolloids and were found maximum at 0.6% concentration. Flat bread prepared with 0.6% GG received higher scores by panelists (4.6) and least were received for SSL flat bread (4.30) at similar concentration. Moreover, with increase in storage period, the scores for colour decreased significantly from 0 to 8<sup>th</sup> day of storage. The colour scores decreased from (4.60 to 4.40) in GG flat bread, from (4.40 to 4.00) in CMC flat bread and from (4.30 to 4.10) in SSL flat bread respectively.

**Table 4.57: Effect of hydrocolloids, storage days on appearance of low-gluten flat bread**

Storage Period (Days)	0.3%				0.6%				0.9%				Mean	Factor
	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub Mean	SSL	GG	CMC	Sub mean		
0	4.100	4.200	4.100	<b>4.133</b>	4.600	4.800	4.700	<b>4.700</b>	4.400	4.600	4.400	<b>4.467</b>	<b>4.433</b>	SSL=4.169
2	4.000	4.100	4.100	<b>4.067</b>	4.400	4.700	4.600	<b>4.567</b>	4.300	4.500	4.300	<b>4.367</b>	<b>4.333</b>	GG=4.300 CMC4.233
4	3.900	4.000	4.033	<b>3.978</b>	4.300	4.600	4.500	<b>4.467</b>	4.200	4.400	4.200	<b>4.267</b>	<b>4.237</b>	
6	3.800	3.900	3.900	<b>3.867</b>	4.200	4.500	4.400	<b>4.367</b>	4.100	4.300	4.100	<b>4.167</b>	<b>4.133</b>	
8	3.700	3.800	3.800	<b>3.767</b>	4.100	4.400	4.300	<b>4.267</b>	3.800	4.200	4.000	<b>4.067</b>	<b>4.033</b>	
<b>Mean</b>	<b>3.90</b>	<b>4.0</b>	<b>3.98</b>	<b>3.962</b>	<b>4.3</b>	<b>4.6</b>	<b>4.5</b>	<b>4.473</b>	<b>4.0</b>	<b>4.4</b>	<b>4.2</b>	<b>4.267</b>		

SSL: (sodium stearyl-2-lactylate),GG: (guar gum) and CMC:(carboxymethyl cellulose)

**C.D (P<0.05)** Days = 0.054  
 B=Hydrocolloid = NS  
 Concentration = 0.042  
 Days × Hydrocolloid = NS  
 Days × Concentration = 0.072  
 Hydr× Concentration = NS  
 Days × Hydr × Conc = NS

**Table 4.58: Effect of hydrocolloids, storage days on colour of low-gluten flat bread**

	0.3%				0.6%				0.9%					
Days	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub Mean	SSL	GG	CMC	Sub mean	Mean	Factor
0	4.067	4.200	4.200	4.156	<b>4.300</b>	4.600	4.400	<b>4.500</b>	4.300	4.400	4.200	<b>4.367</b>	<b>4.341</b>	SSL=4.109 GG=4.220 CMC4.227
2	4.033	4.100	4.000	4.078	<b>4.200</b>	4.500	4.300	<b>4.400</b>	4.207	4.300	4.100	<b>4.302</b>	<b>4.260</b>	
4	3.900	4.033	4.020	3.978	<b>4.100</b>	4.400	4.200	<b>4.300</b>	4.100	4.200	4.000	<b>4.200</b>	<b>4.159</b>	
6	3.800	3.900	3.980	3.867	<b>4.200</b>	4.500	4.100	<b>4.367</b>	4.100	4.300	3.900	<b>4.167</b>	<b>4.133</b>	
8	3.700	3.800	3.700	3.767	<b>4.100</b>	4.400	4.000	<b>4.267</b>	4.000	4.200	3.9200	<b>4.067</b>	<b>4.033</b>	
<b>Mean</b>	<b>3.90</b>	<b>4.07</b>	<b>4.00</b>	<b>3.969</b>	<b>4.18</b>	<b>4.48</b>	<b>4.40</b>	<b>4.367</b>	<b>4.14</b>	<b>4.28</b>	<b>4.24</b>	<b>4.220</b>		

SSL: (sodium stearyl-2-lactylate),GG: (guar gum) and CMC:(carboxymethyl cellulose)

<b>C.D (P&lt;0.05) Days</b>	=	0.053
B=Hydrocolloid	=	0.041
Days × Hydrocolloid	=	0.09
C=Concentration	=	0.041
Days × concentration	=	0.092
Hydr× Concentration	=	0.071
Days ×Hydr×conc	=	0.135

#### **4.3.4.3 Flavour**

The data with regard to organoleptic evaluation for flavor of low gluten optimized flat breads incorporated with different hydrocolloids (Sodium stearoyl-2 lactylate-SSL, Guar gum-GG and carboxymethyl cellulose-CMC) at (0.3%, 0.6% and 0.9%) concentrations during storage for 8 days is depicted in Table 4.59. Data analysis revealed that there was a significant increase in mean scores for flavor in low -gluten optimized flat breads with the incorporation of hydrocolloids and the best scores were noticed at 0.6% concentration., which increased from (4.20 to to 4.30), in CMC flat bread ; from (3.56 to 3.60) in GG flat bread and from (3.88 to 4.20) in SSL flat bread. Further more, with increase in storage period, there was a significant decrease in flavor scores from 0 to 8<sup>th</sup> day and the values ranged from (4.50 to 4.10) in CMC flat bread and from (4.20 to 3.8) in GG flat bread and from (4.30 to 4.20) in SSL flat bread .

#### **4.3.4.4 Texture**

Table 4.60 shows the organoleptic evaluation scores for texture of optimized low-gluten flat breads incorporated with different hydrocolloids (Sodium stearoyl-2 lactylate-SSL, Guar gum-GG and carboxymethyl cellulose-CMC) at (0.3%, 0.6% and 0.9%) concentrations during storage for 8 days. Analysis of data from Table 4.60 revealed that with the increase in hydrocolloid concentration the score for texture increased significantly at 0.6% concentration, the respective mean score was noticed to increase from (4.20 to 4.30 for CMC flat bread (3.56 to 3.60) for GG flat bread (3.88 to 4.1) for SSL flat bread. However with increase in storage period, the scores for texture decreased significantly from 0 to 8<sup>th</sup> day of storage. The scores for texture in GG added flat bread decreased from (3.80 to 3.40) (4.50 to 4.10) in CMC flat bread and from (4.30 to 3.9) in SSL flat bread correspondingly for 0.6% concentration.

**Table 4.59: Effect of hydrocolloids, storage days on flavor of low gluten flat bread**

Storage Period (Days)	0.3%				0.6%				0.9%			Sub mean	Mean	Factor
	SSL	GG	CMC	Sub Mean	SSL	GG	CMC	Sub Mean	SSL	GG	CMC			
0	4.200	4.033	4.300	<b>4.111</b>	4.300	4.200	4.500	<b>4.400</b>	4.2500	4.100	4.300	<b>4.233</b>	<b>4.248</b>	SSL=4.147 GG=4.100 Cmc=3.982
2	4.100	4.200	4.000	<b>4.100</b>	4.2500	4.100	4.400	<b>4.300</b>	4.200	4.000	4.200	<b>4.133</b>	<b>4.178</b>	
4	4.000	4.100	3.900	<b>4.000</b>	4.2000	4.000	4.300	<b>4.200</b>	4.100	3.900	4.100	<b>4.033</b>	<b>4.078</b>	
6	4.000	4.000	3.800	<b>3.933</b>	4.1500	3.900	4.200	<b>4.100</b>	4.000	3.800	4.100	<b>3.967</b>	<b>4.000</b>	
8	3.900	3.900	3.700	<b>3.833</b>	4.1000	3.800	4.100	<b>3.967</b>	3.900	3.700	3.900	<b>3.833</b>	<b>3.878</b>	
<b>Mean</b>	<b>3.88</b>	<b>3.56</b>	<b>4.20</b>	<b>3.996</b>	<b>4.2</b>	<b>3.60</b>	<b>4.30</b>	<b>4.193</b>	<b>4.20</b>	<b>3.46</b>	<b>4.22</b>	<b>4.040</b>		

SSL: (sodium stearyl-2-lactylate),GG: (guar gum) and CMC:(carboxymethyl cellulose)

<b>C.D (P&lt;0.05) Days</b>	=	0.054
Hydrocolloid	=	NS
Concentration	=	0.042
Days × Hydrocolloid	=	NS
Days × concentration	=	0.092
Hydr× Concentration	=	NS
Days x Hydr x Conc	=	NS

**Table 4.60: Effect of hydrocolloids, storage days on texture of low-gluten flat bread**

Storage Period	0.3%				0.6%				0.9%					
(Days)	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub Mean	SSL	GG	CMC	Sub mean	Mean	Factor
0	4.000	3.200	4.400	<b>3.867</b>	4.300	3.800	4.500	<b>4.200</b>	4.200	3.500	<b>4.400</b>	<b>4.03</b>	<b>4.067</b>	SSI=4.069 GG=4.233 CMC=3.540
2	4.000	3.800	4.300	<b>4.033</b>	4.200	3.700	4.400	<b>4.100</b>	4.1800	3.600	<b>4.300</b>	<b>4.02</b>	<b>4.056</b>	
4	3.900	3.700	4.200	<b>3.933</b>	4.100	3.600	4.300	<b>4.000</b>	4.0867	3.500	<b>4.200</b>	<b>3.92</b>	<b>3.974</b>	
6	3.800	3.600	4.100	<b>3.833</b>	4.000	3.500	4.200	<b>3.900</b>	3.96	3.400	<b>4.100</b>	<b>3.82</b>	<b>3.878</b>	
8	3.700	3.500	4.000	<b>3.733</b>	3.900	3.400	4.100	<b>3.800</b>	3.89	3.300	<b>4.000</b>	<b>3.73</b>	<b>3.763</b>	
<b>Mean</b>	<b>3.88</b>	<b>3.56</b>	<b>4.20</b>	<b>3.880</b>	<b>4.10</b>	<b>3.60</b>	<b>4.30</b>	<b>4.000</b>	<b>4.06</b>	<b>3.46</b>	<b>4.20</b>	<b>3.90</b>		

SSL: (sodium stearyl-2-lactylate), GG: (guar gum) and CMC:(carboxymethyl cellulose)

<b>C.D (P&lt;0.05) Days</b>	=	0.054
Hydrocolloid	=	0.042
Concentration	=	0.042
Days × Hydrocolloid	=	0.094
Days × concentration	=	0.094
Hydr × Concentration	=	0.073
Days x Hydr x Conc	=	0.163

#### **4.3.4.5 Hardness**

The data analogous to hardness of optimized low gluten flat breads based on 5 point Hedonic scale, incorporated with different hydrocolloids (Sodium stearoyl-2 lactylate-SSL, guar gum-GG and carboxymethyl cellulose-CMC) at (0.3%, 0.6% and 0.9%) concentrations during storage for 8 days are presented in Table 4.61. Analysis of data revealed that hardness scores increased with the addition of hydrocolloids and were found maximum at 0.6% concentration. Optimized low- gluten flat bread prepared with 0.6% GG received higher scores by panelists (4.6) and least were received for SSL flat bread (4.30) at similar concentration. Moreover, with increase in storage period, the scores for hardness decreased significantly from 0 to 8<sup>th</sup> day of storage. The hardness scores decreased from (4.80 to 4.40) in GG flat bread, from (4.40 to 4.00) in CMC flat bread and from (4.50 to 4.10) in SSL flat bread in that order.

#### **4.3.4.6 Staling**

The data with regard to staling of low-gluten optimized flat breads incorporated with different hydrocolloids (Sodium stearoyl-2 lactylate-SSL, Guar gum-GG and carboxymethyl cellulose-CMC) at (0.3%, 0.6% and 0.9%) concentrations during storage for 8 days is depicted in Table 4.62. Data analysis revealed that there was a significant increase in mean scores for staling in low gluten flat breads with the incorporation of hydrocolloids and the best scores were noticed at 0.6% concentration., which increased from (3.2 to to 3.6), in CMC flat bread from (4.1 to 4.4) in GG flat bread and from (4.0 to 4.3) in SSI flat bread. Further more, with increase in storage period, there was a significant decrease in staling scores from 0 to 8<sup>th</sup> day and the values ranged from (4.50 to 4.10) in SSL flat bread and from (4.6 to 4.2) in GG flat bread.and from (3.80 to 3.50) in CMC flat bread correspondingly.

**Table 4.61: Effect of hydrocolloids, storage days on hardness of low-gluten flat bread**

Storage Period (Days)	0.3%				0.6%				0.9%			Sub mean	Mean	Factor
	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub Mean	SSL	GG	CMC			
0	4.100	4.500	4.100	<b>4.233</b>	4.500	4.800	4.400	<b>4.567</b>	4.500	4.600	4.200	<b>4.433</b>	<b>4.411</b>	SSL=4.200
2	4.000	4.400	4.000	<b>4.133</b>	4.400	4.700	4.300	<b>4.467</b>	4.400	4.500	4.100	<b>4.333</b>	<b>4.311</b>	GG=4.449
4	4.000	4.300	3.900	<b>4.067</b>	4.300	4.600	4.200	<b>4.367</b>	4.300	4.400	4.000	<b>4.233</b>	<b>4.222</b>	CMC=4.047
6	4.000	4.200	3.800	<b>4.000</b>	4.200	4.500	4.100	<b>4.267</b>	4.200	4.433	4.000	<b>4.211</b>	<b>4.159</b>	
8	3.900	4.100	3.700	<b>3.900</b>	4.100	4.400	4.000	<b>4.167</b>	4.100	4.300	3.900	<b>4.100</b>	<b>4.056</b>	
<b>Mean</b>	<b>4.0</b>	<b>4.30</b>	<b>3.9</b>	<b>4.067</b>	<b>4.30</b>	<b>4.60</b>	<b>4.20</b>	<b>4.367</b>	<b>4.30</b>	<b>4.44</b>	<b>4.04</b>	<b>4.262</b>		

SSL: (sodium stearyl-2-lactylate), GG: (guar gum) and CMC:(carboxymethyl cellulose)

<b>C.D (P&lt;0.05) Days</b>	=	0.054
Hydrocolloid	=	0.042
Concentration	=	0.042
Days × Hydrocolloid	=	0.096
Days × concentration	=	0.096
Hydr× Concentration	=	0.082
Days ×Hyd ×Conc	=	0.134

**Table 4.62: Effect of hydrocolloids, storage days on staling of low-gluten flat bread**

Storage Period (Days)	0.3%				0.6%				0.9%		Mean	Factor	
	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub Mean	SSL	GG			
0	4.100	4.200	3.200	<b>4.033</b>	4.500	4.600	3.800	<b>4.100</b>	4.200	4.500	3.500	<b>4.06</b>	SSL=4.194 GG=4.267 CMC3.407
2	4.000	4.100	3.100	<b>3.967</b>	4.400	4.500	3.800	<b>4.000</b>	4.110	4.400	3.400	<b>3.97</b>	
4	4.000	4.100	3.000	<b>3.933</b>	4.300	4.400	3.700	<b>3.900</b>	4.000	4.300	3.300	<b>3.86</b>	
6	4.000	4.100	3.000	<b>3.900</b>	4.200	4.300	3.600	<b>3.833</b>	3.900	4.200	3.200	<b>3.76</b>	
8	3.900	4.000	3.900	<b>3.800</b>	4.100	4.200	3.500	<b>4.067</b>	3.800	4.100	3.100	<b>3.66</b>	
<b>Mean</b>	<b>4.0</b>	<b>4.1</b>	<b>3.2</b>	<b>3.927</b>	<b>4.3</b>	<b>4.4</b>	<b>3.6</b>	<b>3.980</b>	<b>4.0</b>	<b>4.3</b>	<b>3.3</b>	<b>3.86</b>	

SSL: (sodium stearyl-2-lactylate),GG: (guar gum) and CMC:(carboxymethyl cellulose)

<b>C.D (P&lt;0.05) Days</b>	=	0.054
Hydrocolloid	=	0.042
Concentration	=	0.042
Days × Hydrocolloid	=	0.094
Days × concentration	=	0.094
Hydr× Concentration	=	0.073
Days × Hydr × conc	=	0.162

#### **4.3.4.7 Overall acceptability**

Table 4.63 shows the organoleptic evaluation scores of hydrocolloid incorporated optimized low-gluten flat breads. Overall acceptability scores in terms of appearance, flavor, color, texture, hardness and staling, were found significantly ( $p \leq 0.05$ ) higher in all hydrocolloid incorporated low-gluten flat breads viz (Sodium stearoyl-2 lactylate-SSL, Guargum-GG and carboxymethyl cellulose-CMC) at (0.3%, 0.6% and 0.9%) concentrations during storage for 8 days. Analysis of data revealed that overall acceptability scores were found higher in GG flat bread (4.6) on 0 day of storage followed by CMC flat bread (4.5) and (4.1) in SSL flat bread. Moreover with increase in storage period the scores for overall acceptability were found to decrease, higher decrease was noticed from (4.1 to 3.93) in SSL flat bread from (4.6 to 4.2) in GG flat bread and from (4.6 to 4.2) in CMC flat bread respectively.

**Table 4.63: Effect of hydrocolloids, storage days on overall acceptability of low-gluten flat bread**

Storage Period (Days)	0.3%				0.6%				0.9%			Mean	Factor	
	SSL	GG	CMC	Sub mean	SSL	GG	CMC	Sub Mean	SSL	GG	CMC			Sub mean
0	3.900	4.200	4.100	<b>4.067</b>	4.100	4.600	4.500	<b>4.400</b>	4.033	4.400	4.400	<b>4.278</b>	4.248	SSL=4.136 GG=4.240 CMC=3.904
2	4.010	4.130	4.050	<b>4.063</b>	4.050	4.530	4.290	<b>4.290</b>	3.960	4.360	4.270	<b>4.197</b>	4.183	
4	3.900	4.050	3.980	<b>3.977</b>	3.950	4.430	4.230	<b>4.203</b>	3.893	4.260	4.210	<b>4.121</b>	4.100	
6	3.810	3.960	3.950	<b>3.907</b>	3.860	4.330	4.130	<b>4.107</b>	3.780	4.180	4.110	<b>4.023</b>	4.012	
8	3.710	3.860	3.850	<b>3.807</b>	3.930	4.230	4.010	<b>4.057</b>	3.680	4.080	3.960	<b>3.907</b>	3.923	
<b>Mean</b>	<b>3.86</b>	<b>4.04</b>	<b>3.98</b>	<b>3.964</b>	<b>3.97</b>	<b>4.42</b>	<b>4.23</b>	<b>4.211</b>	<b>3.86</b>	<b>4.25</b>	<b>4.19</b>	<b>4.105</b>		

SSL: (sodium stearyl-2-lactylate), GG: (guar gum) and CMC:(carboxymethyl cellulose)

<b>C.D (P≤0.05) Days</b>	=	0.026
Hydrocolloid	=	0.020
Concentration	=	0.020
Days × Hydrocolloid	=	0.046
Days × concentration	=	0.046
Hydrocolloid × Concentration	=	0.035
Days × Hydrocolloid × conc	=	0.079

#### **4.4 Experiment No. IV: To study the effect of storage conditions and packaging material on the stability of low-gluten flat bread**

The low-gluten hydrocolloid incorporated flat bread viz (Guar gum at 0.6%) was packed in metalized polyester film (MPE) and stored under ambient (20 to 25°C, 50%RH) and accelerated (38°C, 75-80%RH) conditions for a period of 10 days. The stored sample was compared with control viz (traditionally flat bread) and was analyzed for following physicochemical parameters at an interval of 2 days.

##### **4.4.1 Water activity**

Table 4.64 presents the effect of storage conditions (ambient and accelerated) and packaging materials on the stability of control flat bread (CFB) and hydrocolloids incorporated flat bread (HFB). Analysis of data illustrated that water activity was found to decrease non-significantly ( $p \leq 0.05$ ) in both CFB and HFB breads under both the storage conditions. Water activity decreased from 0.85 to 0.75 and 0.88 to 0.78, in control and hydrocolloid incorporated flat breads, respectively stored under ambient conditions. Accelerated storage however, resulted in less decrease of water activity compared to that under ambient storage conditions. Water activity decreased from 0.85 to 0.78 and 0.88 to 0.80 in CFB and HFB flat breads, respectively under accelerated storage conditions for the period of 10 days.

##### **4.4.2 Moisture content**

Table 4.65 depicted decrease of moisture content during storage days, irrespective of the type of storage conditions and packaging material used for the study. However, decrease in the moisture was found more in control flat bread under ambient storage conditions compared to accelerated storage. Under ambient conditions, moisture content in CFB decreased from 31.32 to 20.42 % and 33.35 to 27.13% in HFB. However in accelerated conditions less decrease in moisture content was noticed for HFB and the values ranged from 33.35 to 29.11%.after 10 days of storage.

**Table 4.64: Effect of storage conditions and packaging material on water activity of low-gluten flat bread**

CFB				HFB			Overall Mean	Factor mean
Storage Days	Ambient	Accelerated	Sub mean	Ambient	Accelerated	Sub mean		
0	0.85	0.85	<b>0.85</b>	0.88	0.88	<b>0.88</b>	<b>0.86</b>	Amb=0.83 ACC=0.81
2	0.82	0.84	<b>0.82</b>	0.85	0.87	<b>0.86</b>	<b>0.84</b>	
4	0.80	0.83	<b>0.81</b>	0.83	0.85	<b>0.84</b>	<b>0.82</b>	
6	0.79	0.82	<b>0.80</b>	0.81	0.84	<b>0.82</b>	<b>0.81</b>	
8	0.78	0.80	<b>0.79</b>	0.80	0.82	<b>0.81</b>	<b>0.80</b>	
10	0.75	0.78	<b>0.77</b>	0.78	0.80	<b>0.79</b>	<b>0.78</b>	
<b>Mean</b>	<b>0.80</b>	<b>0.82</b>	<b>0.80</b>	<b>0.82</b>	<b>0.84</b>	<b>0.83</b>	<b>0.81</b>	

Where CFB= Control Flat bread ;HFB = Hydrocolloid added flat bread (Guar gum);Ambient =(20°C,50%RH); Accelerated (38°C,75-80%RH)

**C.D(p<0.05)** Sample type: (S) = 0.002  
 Days: (D) = 0.003  
 Cond : (C) = 0.004  
 S × D = 0.004  
 S × C = 0.006  
 D × C = 0.007  
 S × D × C = 0.009

**Table 4.65: Effect of storage conditions and packaging material on moisture content of low-gluten flat bread**

Storage Days	CFB			HFB			Overall Mean	Factor
	Ambient	Accelerated	Sub mean	Ambient	Accelerated	Sub mean		
0	31.32	31.32	<b>30.81</b>	33.35	33.35	<b>32.90</b>	<b>31.85</b>	Amb=29.00 Acc=27.57
2	28.63	30.29	<b>29.46</b>	31.42	33.30	<b>32.36</b>	<b>30.91</b>	
4	25.57	28.65	<b>27.11</b>	30.50	31.20	<b>30.85</b>	<b>28.98</b>	
6	23.18	26.67	<b>24.92</b>	29.25	30.18	<b>29.71</b>	<b>27.32</b>	
8	22.33	24.51	<b>23.42</b>	28.61	29.28	<b>28.94</b>	<b>26.18</b>	
10	20.42	22.19	<b>21.30</b>	27.13	29.11	<b>27.65</b>	<b>24.47</b>	
<b>Mean</b>	<b>25.24</b>	<b>27.27</b>	<b>26.17</b>	<b>30.04</b>	<b>31.91</b>	<b>30.40</b>		

Where CFB= Control Flat bread ;HFB = Hydrocolloid added flat bread with (Guar gum); Ambient =(20°C,50%RH); Accelerated (38°C,75-80%RH)

**C.D(p<0.05)** Sample type: (S) = 0.020  
 Days : (D) = 0.034  
 Condition : (C) = 0.020  
 S × C = 0.028  
 S × D = 0.048  
 D × C = 0.048  
 S × D × C = 0.069

### 4.4.3 EMC and ERH

Equilibrium moisture content (EMC) and Equilibrium relative humidity (ERH) data obtained for Control flat bread (CFB) and hydrocolloid incorporated flat bread (HFB) at two different storage conditions ambient and accelerated are presented in Table 4.66 and the moisture sorption isotherms based on EMC and ERH values are shown in Fig 4.22. Results revealed that the moisture content of both CFB and HFB decreased as the temperature increased. Further, the EMC and ERH was observed to be lower in CFB under accelerated conditions in comparison to HFB.

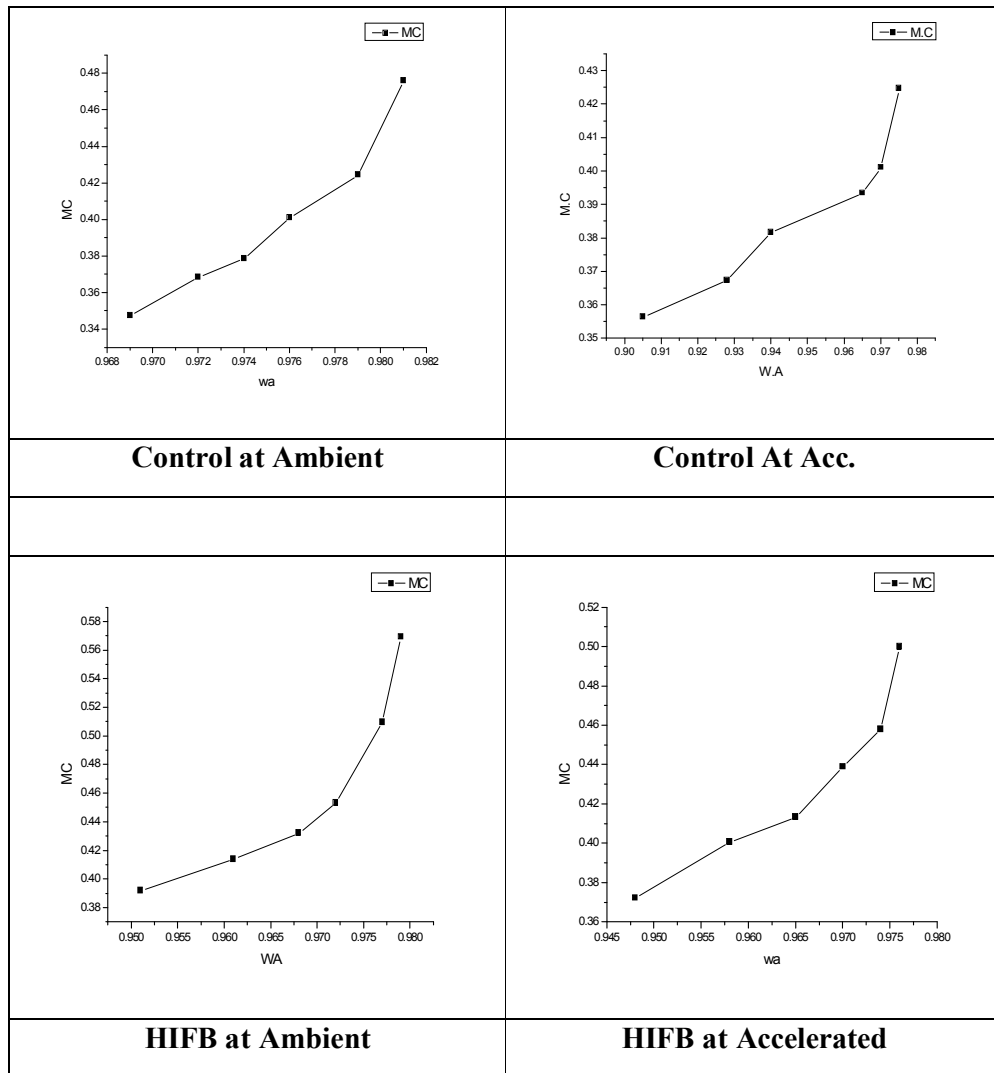
**Table 4.66: EMC and ERH (%) based on sorption isotherm during storage**

Sorption values	CFB		HFB	
	Ambient	Accelerated	Ambient	Accelerated
EMC %	29.57	28.57	33.99	31.50
ERH%	98.00	97.50	97.90	97.30
<b>Mean</b>	<b>63.78</b>	<b>63.03</b>	<b>65.94</b>	<b>64.40</b>

### 4.4.4 Instrumental colour( $L^*,a^*,b^*$ )

#### 4.4.4.1 Luminosity ( $L^*$ value)

The data regarding the effect of storage conditions (ambient and accelerated), packaging material on luminosity ( $L^*$  value) of control flat bread (CFB) and hydrocolloid incorporated flat bread (HFB) are presented in Table 4.67. Analysis of data revealed that luminosity ( $L^*$  value) was found to decrease in both CFB and HFB breads under both the storage conditions.. However, there was more decrease in luminosity ( $L^*$  value) in case of the CFB stored at accelerated condition during the storage period of 10 days. Luminosity ( $L^*$  value) of control decreased from 46.65 to 41.30 stored at ambient condition while as it decreased from 46.65 to 39.41 in case of accelerated conditions. while as at accelerated condition, it luminosity ( $L^*$  value) of HFB stored at ambient condition



HFB = Hydrocolloid flat bread

**Fig. 4.22: Sorption isotherms under ambient and accelerated conditions**

decreased from 47.75 to 44.35 while as at accelerated condition, it decreased from 47.75 to 40.58 at the end of storage period.

#### **4.4.4.2 Redness ( $a^*$ value)**

Table 4.68 shows the effect of storage conditions (ambient and accelerated) and packaging materials on the the redness ( $a^*$ ) values of control flat bread (CFB) and hydrocolloids incorporated flat bread (HFB). Analysis of data illustrated that redness ( $a^*$ ) was found to increase in both CFB and HFB breads under both the storage conditions. Redness ( $a^*$ ) value increased from 3.85 to 4.55 and 3.75 to 4.25, in control and hydrocolloid incorporated flat breads respectively, stored under ambient conditions. Accelerated storage however, resulted in more increase of redness compared to that under ambient storage conditions. Redness ( $a^*$ ) increased from to 3.85 to 4.95 in CFB and from 3.75 to 4.15 in HFB flat breads, respectively under accelerated storage conditions for the period of 10 days.

#### **4.4.4.3 Yellowness ( $b^*$ value)**

The data regarding the effect of storage conditions (ambient and accelerated), packaging material on yellowness ( $b^*$  value) of control flat bread (CFB) and hydrocolloid incorporated flat bread (HFB) are presented in Table 4.69. Analysis of data revealed that yellowness ( $b^*$  value) was found to decrease in both CFB and HFB breads under both the storage conditions. However, there was more decrease in yellowness ( $b^*$  value) in case of HFB stored at accelerated condition during the storage period of 10 days. Yellowness ( $b^*$  value) of CFB decreased from 29.55 to 26.55 stored at ambient condition while as it decreased from 29.55 to 25.15 in case of accelerated conditions. while as at accelerated condition, it yellowness ( $b^*$  value) of HFB stored at ambient condition decreased from 28.13 to 24.05 while as at accelerated condition, it decreased from 28.13 to 20.01 at the end of storage period.

**Table 4.67: Effect of storage conditions and packaging material on  $L^*$  value of low-gluten flat bread**

CFB				HFB			Overall Mean	Factor mean
Storage Days	Ambient	Accelerated	Sub mean	Ambient	Accelerated	Sub mean		
0	46.65	46.65	<b>46.62</b>	47.75	47.75	<b>47.73</b>	<b>47.18</b>	Amb=45.59 Acc.=43.97
2	46.02	45.57	<b>46.09</b>	47.72	46.65	<b>47.18</b>	<b>46.64</b>	
4	45.72	45.01	<b>45.36</b>	46.60	45.19	<b>45.89</b>	<b>45.63</b>	
6	45.08	44.87.	<b>45.06</b>	45.69	44.48	<b>43.78</b>	<b>44.42</b>	
8	43.12	41.45	<b>45.06</b>	45.19	42.35	<b>41.97</b>	<b>43.51</b>	
10	41.30	39.41	<b>43.72</b>	44.35	40.58	<b>38.91</b>	<b>41.31</b>	
<b>Mean</b>	<b>44.64</b>	<b>43.82</b>	<b>45.32</b>	<b>45.50</b>	<b>44.50</b>	<b>44.24</b>		

Where CFB= Control Flat bread ;HFB = Hydrocolloid added flat bread with (Guar gum);Ambient =(20°C,50%RH); Accelerated (38°C,75-80%RH)

**C.D(p<0.05)** Sample type : (S) = 0.215  
 Condition : (C) = 0.372  
 Days : (D) = 0.215  
 S × C = 0.526  
 S × D = 0.303  
 D × C = 0.526.  
 S × D × C = 0.743

**Table 4.68: Effect of storage conditions and packaging material on  $a^*$  value of low-gluten flat bread**

Storage Days	CFB			HFB			Overall Mean	Factor mean
	Ambient	Accelerated	Sub mean	Ambient	Accelerated	Sub mean		
0	3.85	3.85	<b>3.85</b>	3.75	3.75	<b>3.75</b>	<b>3.86</b>	Amb=4.04 Acc=4.19
2	3.95	3.97	<b>3.96</b>	3.90	3.89	<b>3.89</b>	<b>3.92</b>	
4	3.97	4.05	<b>4.01</b>	3.95	3.92	<b>3.93</b>	<b>3.97</b>	
6	4.01	4.57	<b>4.29</b>	3.99	3.97	<b>3.98</b>	<b>4.13</b>	
8	4.49	4.79	<b>4.64</b>	4.08	4.01	<b>4.04</b>	<b>4.34</b>	
10	4.55	4.95	<b>4.75</b>	4.25	4.15	<b>4.2</b>	<b>4.47</b>	
<b>Mean</b>	<b>4.12</b>	<b>4.34</b>	<b>4.25</b>	<b>4.00</b>	<b>3.96</b>	<b>3.98</b>		

Where CFB= Control Flat bread ; HFB = Hydrocolloid added flat bread with (Guar gum); Ambient =(20°C,50%RH); Accelerated (38°C,75-80%RH)

**C.D(p<0.05)** Sample type : (S) = 0.012  
 Condition : (C) = 0.012  
 Days : (D) = 0.020  
 S × C = 0.017  
 S × D = 0.029  
 D × C = 0.029  
 S × D × C = 0.041

**Table 4.69: Effect of storage conditions and packaging material on  $b^*$  value of low-gluten flat bread**

Storage Days	CFB			(HFB)			Overall Mean	Factor
	Ambient	Accelerated	Sub mean	Ambient	Accelerated	Sub mean		
0	29.55	29.55	<b>29.55</b>	28.13	28.13	<b>28.13</b>	<b>28.84</b>	Amb=26.92 Acc=25.42
2	29.05	28.45	<b>28.75</b>	27.09	25.85	<b>26.47</b>	<b>27.61</b>	
4	28.45	27.84	<b>28.14</b>	25.09	24.45	<b>24.77</b>	<b>26.45</b>	
6	27.75	27.24	<b>27.49</b>	25.79	22.17	<b>23.98</b>	<b>25.73</b>	
8	27.45	26.65	<b>27.05</b>	24.18	20.52	<b>22.35</b>	<b>24.70</b>	
10	26.55	25.15	<b>25.85</b>	24.05	20.01	<b>22.03</b>	<b>23.94</b>	
<b>Mean</b>	<b>28.13</b>	<b>27.48</b>	<b>27.76</b>	<b>25.72</b>	<b>23.52</b>	<b>24.59</b>		

Where CFB= Control Flat bread ;HFB = Hydrocolloid added flat bread with (Guar gum);Ambient =(20°C,50%RH); Accelerated (38°C,75-80%RH)

**C.D(p<0.05)** Sample type : (S) = 0.009  
 Condition : (C) = 0.009  
 Days : (D) = 0.016  
 S × C = 0.013  
 S × D = 0.023  
 D × C = 0.023  
 S × D × C = 0.032

#### **4.4.5 Resistant starch**

Table 4.70 shows the effect of storage conditions (ambient and accelerated), packaging material on resistant starch of control flat bread (CFB) and hydrocolloid incorporated flat bread (HFB). Analysis of data revealed that resistant starch content of both CFB and HFB increased with increase in the duration of storage. Resistant starch content increased from 1.17 to 1.30 % in (CFB) and from 1.15 to 1.27% in (HFB) at ambient storage conditions. Compared to ambient storage conditions, accelerated conditions resulted in more increase in resistant starch content in control flat bread compared to hydrocolloid flat bread. Resistant starch content of CFB increased from 1.17 to 1.34% in HFB and from 1.15 to 1.32% after 10 days of storage period under accelerated conditions.

#### **4.4.6 Starch**

Analysis of data regarding the effect of storage conditions (ambient and accelerated), packaging material and storage days on starch content of control flat bread (CFB) and hydrocolloid incorporated flat bread (HFB) is depicted in Table 4.71 with increase in storage days starch content was found to be decreased in both CFB and HFB under ambient and accelerated conditions. However, decrease in the starch content was found more in control flat bread under accelerated storage conditions compared to ambient conditions. Under ambient conditions starch content in CFB decreased from 65.01 to 56.18 % and 66.25 to 259.11% in HFB. However in accelerated conditions less decrease in starch content was noticed for HFB and the values ranged from 66.25 to 55.30 % after 10 days of storage.

**Table 4.70: Effect of storage conditions and packaging material on resistant starch of low gluten flat bread**

CFB				(HFB)			Overall Mean	Factor
Storage Days	Ambient	Accelerated	Sub mean	Ambient	Accelerated	Sub mean		
0	1.15	1.15	<b>1.15</b>	1.17	1.17	<b>1.17</b>	<b>1.16</b>	Amb=1.21 Acc=1.26
2	1.17	1.19	<b>1.18</b>	1.19	1.22	<b>1.20</b>	<b>1.19</b>	
4	1.19	1.24	<b>1.21</b>	1.21	1.26	<b>1.23</b>	<b>1.22</b>	
6	1.22	1.27	<b>1.25</b>	1.24	1.29	<b>1.26</b>	<b>1.25</b>	
8	1.24	1.30	<b>1.27</b>	1.26	1.32	<b>1.29</b>	<b>1.28</b>	
10	1.27	1.32	<b>1.30</b>	1.30	1.34	<b>1.32</b>	<b>1.31</b>	
<b>Mean</b>	<b>1.20</b>	<b>1.24</b>	<b>1.23</b>	<b>1.22</b>	<b>1.26</b>	<b>1.24</b>		

Where CFB= Control Flat bread ; HFB = Hydrocolloid added flat bread with (Guar gum); Ambient =(20°C,50%RH); Accelerated (38°C,75-80%RH)

**C.D(p<0.05)** Sample type : (S) = 0.005  
 Condition : (C) = 0.005  
 Days : (D) = 0.008  
 S × C = 0.01  
 S × D = 0.013  
 D × C = 0.013  
 S × D × C = 0.018

**Table 4.71: Effect of storage conditions and packaging material on starch of low-gluten flat bread**

Storage Days	CFB			(HFB)			Overall Mean	Factor
	Ambient	Accelerated	Sub mean	Ambient	Accelerated	Sub mean		
0	65.01	65.01	<b>65.01</b>	66.25	66.25	<b>66.25</b>	<b>65.63</b>	Amb=61.44 Acc=60.27
2	64.30	63.88	<b>64.09</b>	65.15	64.11	<b>64.63</b>	<b>64.36</b>	
4	62.28	60.13	<b>61.20</b>	63.32	61.18	<b>62.25</b>	<b>61.72</b>	
6	60.51	58.25	<b>59.38</b>	62.55	59.22	<b>60.88</b>	<b>60.13</b>	
8	58.25	56.42	<b>57.35</b>	60.40	58.41	<b>59.40</b>	<b>58.37</b>	
10	56.18	54.12	<b>55.15</b>	59.11	55.30	<b>57.20</b>	<b>56.17</b>	
<b>Mean</b>	<b>61.08</b>	<b>59.63</b>	<b>60.36</b>	<b>63.79</b>	<b>61.74</b>	<b>61.76</b>		

Where CFB= Control Flat bread ;HFB = Hydrocolloid added flat bread with (Guar gum);Ambient =(20°C,50%RH); Accelerated (38°C,75-80%RH)

**C.D(p<0.05)** Sample type : (S) = 0.237  
 Condition : (C) = 0.237  
 Days : (D) = 0.410  
 S × C = 0.335  
 S × D = 0.581  
 D × C = 0.581  
 S × D × C = 0.821

#### **4.4.7 Spread ratio**

Spread ratio of both of control flat bread (CFB) and hydrocolloid incorporated flat bread (HFB) decreased significantly ( $p \leq 0.05$ ) under both storage conditions (ambient and accelerated). More decrease in spread ratio was observed in CFB stored under accelerated conditions than those stored under ambient conditions (Table 4.72). Spread ratio decreased from 14.50 to 14.42 (in CFB) at ambient conditions and from 14.50 to 14.00 at accelerated conditions. However in case of HFB spread ratio decreased from 15.50 to 14.63 at ambient conditions and from 15.50 to 14.61 under accelerated storage conditions during 10 days of storage period.

#### **4.4.8 Texture profile analysis**

Table 4.73 to Table 4.77 demonstrates the effect of storage conditions (ambient and accelerated), packaging material and storage days on textural properties of control flat bread (CFB) and hydrocolloid incorporated flat bread (HFB). Hardness of both CFB and HFB increased significantly ( $p \leq 0.05$ ) with increase in storage period (Table 4.73). Increase in hardness was slower in HFB stored under ambient conditions, with increase in hardness from 8.25 N to 9.68N and 8.25 to 10.58 N under accelerated conditions, compared to CFB under ambient conditions and accelerated conditions. Hardness of CFB increased from 8.33N to 11.89 N in (ambient conditions) and from 8.33N to 12.63 N, respectively under accelerated storage conditions. It was therefore, obvious from the results that the flat breads stored under accelerated conditions were harder compared to flat bread stored under ambient storage conditions.

The results regarding the effect of storage conditions, packaging material and storage duration on cohesiveness of control flat bread (CFB) and hydrocolloid incorporated flat bread (HFB) are depicted in (Table 4.74). Cohesiveness of both CFB and HFB was found to decrease significantly ( $p \leq 0.05$ ) with increase in the duration of storage. More decrease was however observed in CFB than HFB from

0.69 to 0.62 and from 0.72 to 0.67 correspondingly under ambient storage conditions for 10 days of storage period.

Springiness, also referred to as elasticity, is a perception of gel rubberiness in the mouth and is a measure of how much a gel structure is broken down by the initial compression (Sanderson, 1990). As observed from (Table 4.75), Springiness decreased non-significantly ( $p \leq 0.05$ ) from 0.87 to 0.82mm; and from 0.88 to 0.83 mm respectively in control flat bread (CFB) and hydrocolloid incorporated flat bread (HFB) after 10 days of storage under ambient storage conditions. Compared to ambient storage conditions, the decreases in springiness was more in accelerated storage conditions. Springiness was found to decrease from 0.87 to 0.81mm and 0.88 to 0.82 mm in CFB and HFB, respectively.

Gumminess of both of control flat bread (CFB) and hydrocolloid incorporated flat bread (HFB) increased significantly ( $p \leq 0.05$ ) under both storage conditions (ambient and accelerated) (Table 4.76). More increase was, however, observed in samples stored under accelerated conditions compared to ambient storage conditions. Gumminess was found to increase more in CFB from 5.94 to 7.01 N under accelerated conditions in comparison to HFB from 5.64 to 6.66N under same accelerated conditions.

Chewiness is the quantity to stimulate the energy required for masticating a semi-solid sample to a steady-state for swallowing (Sang *et al.*, 2014). With increase in the storage period under both ambient and accelerated conditions, chewiness of control flat bread (CFB) and hydrocolloid incorporated flat bread (HFB) increased significantly ( $p \leq 0.05$ ) under both storage conditions (ambient and accelerated) (Table 4.77). Chewiness of CFB increased from 5.22N to 5.69 N in (ambient conditions) and from 5.22N to 5.74 N, under accelerated storage conditions. However in case of HFB chewiness increased from 4.90N to 5.15 N in (ambient conditions) and from 4.90N to 5.39N, under accelerated storage conditions during 10 days of storage period.

**Table 4.72: Effect of storage conditions and packaging material on spread ratio of low-gluten flat bread**

CFB				HFB			Overall Mean	Factor
Storage Days	Ambient	Accelerated	Sub mean	Ambient	Accelerated	Sub mean		
0	14.53	14.50	<b>14.51</b>	15.50	15.48	<b>15.49</b>	<b>15.00</b>	Amb=14.75 ACC=14.42
2	14.50	14.48	<b>14.49</b>	15.42	15.40	<b>15.41</b>	<b>14.95</b>	
4	14.49	14.46	<b>14.47</b>	15.00	14.90	<b>14.95</b>	<b>14.71</b>	
6	14.47	14.43	<b>14.45</b>	14.91	14.89	<b>14.90</b>	<b>14.67</b>	
8	14.45	14.41	<b>14.43</b>	14.72	14.70	<b>14.71</b>	<b>14.57</b>	
10	14.42	14.00	<b>14.21</b>	14.63	14.61	<b>14.62</b>	<b>14.41</b>	
<b>Mean</b>	<b>14.47</b>	<b>14.38</b>	<b>14.28</b>	<b>15.03</b>	<b>14.99</b>	<b>15.01</b>		

Where CFB= Control Flat bread ;HFB = Hydrocolloid added flat bread with (Guar gum);Ambient =(20°C,50%RH); Accelerated (38°C,75-80%RH)

**C.D(p<0.05)** Sample type : (S) = 0.028  
 Condition : (C) = NS  
 Days : (D) = 0.048  
 S × C = NS  
 S × D = 0.068  
 D × C = 0.068  
 S × D × C = NS

**Table 4.73: Effect of storage conditions and packaging material on hardness of low-gluten flat bread**

CFB				(HFB)			Overall Mean	Factor
Storage Days	Ambient	Accelerated	Sub mean	Ambient	Accelerated	Sub mean		
0	8.33	8.33	<b>8.33</b>	8.25	8.25	<b>8.25</b>	8.29	Amb=9.13 Acc=9.44
2	8.48	8.75	<b>8.61</b>	8.44	8.70	<b>8.57</b>	8.59	
4	8.81	9.15	<b>8.98</b>	8.69	9.08	<b>8.93</b>	8.95	
6	9.65	9.78	<b>9.51</b>	9.30	9.63	<b>9.46</b>	9.49	
8	9.85	10.20	<b>10.02</b>	9.55	10.15	<b>9.98</b>	10.03	
10	11.89	12.63	<b>10.43</b>	9.68	10.58	<b>10.35</b>	10.39	
<b>Mean</b>	<b>9.45</b>	<b>9.80</b>	<b>9.31</b>	<b>8.98</b>	<b>9.41</b>	<b>9.26</b>		

Where CFB= Control Flat bread ;HFB = Hydrocolloid added flat bread with (Guar gum);Ambient =(20°C,50%RH); Accelerated (38°C,75-80%RH).

**C.D (p<0.05)** Sample type : (S) = 0.020  
 Condition : (C) = 0.020  
 Days : (D) = 0.034  
 S × C = 0.035  
 S × D = 0.05  
 D × C = 0.049  
 S × D × C = 0.07

**Table 4.74: Effect of storage conditions and packaging material on cohesiveness of low-gluten flat bread**

CFB			HFB			Overall Mean	Factor
Storage Days	Ambient	Accelerated	Sub mean	Ambient	Accelerated		
0	0.69	0.69	<b>0.69</b>	0.72	0.72	<b>0.72</b>	Amb=0.678 ACC=0.670
2	0.68	0.67	<b>0.67</b>	0.71	0.70	<b>0.70</b>	
4	0.67	0.66	<b>0.66</b>	0.70	0.69	<b>0.69</b>	
6	0.65	0.64	<b>0.64</b>	0.69	0.68	<b>0.68</b>	
8	0.64	0.63	<b>0.63</b>	0.68	0.67	<b>0.67</b>	
10	0.63	0.62	<b>0.62</b>	0.67	0.66	<b>0.66</b>	
<b>Mean</b>	<b>0.66</b>	<b>0.65</b>	<b>0.65</b>	<b>0.69</b>	<b>0.68</b>	<b>0.69</b>	

Where CFB= Control Flat bread ;HFB = Hydrocolloid added flat bread with (Guar gum);Ambient =(20°C,50%RH); Accelerated (38°C,75-80%RH).

**C.D(p<0.05)** Sample type : (S) = 0.020  
 Condition : (C) = 0.034  
 Days : (D) = 0.020  
 S × C = 0.050  
 S × D = 0.040  
 D × C = 0.049  
 S × D × C = 0.069

**Table 4.75: Effect of storage conditions and packaging material on springiness low-gluten flat bread.**

CFB				HFB			Overall Mean	Factor
Storage Days	Ambient	Accelerated	Sub mean	Ambient	Accelerated	Sub mean		
0	0.87	0.87	<b>0.87</b>	0.88	0.88	<b>0.88</b>	<b>0.87</b>	<b>Amb=0.85</b> <b>Acc=0.84</b>
2	0.86	0.85	<b>0.85</b>	0.87	0.86	<b>0.86</b>	<b>0.86</b>	
4	0.85	0.84	<b>0.84</b>	0.86	0.85	<b>0.85</b>	<b>0.85</b>	
6	0.84	0.83	<b>0.83</b>	0.85	0.84	<b>0.84</b>	<b>0.84</b>	
8	0.83	0.82	<b>0.82</b>	0.84	0.83	<b>0.83</b>	<b>0.83</b>	
10	0.82	0.81	<b>0.81</b>	0.83	0.82	<b>0.82</b>	<b>0.82</b>	
<b>Mean</b>	<b>0.84</b>	<b>0.83</b>	<b>0.84</b>	<b>0.85</b>	<b>0.84</b>	<b>0.85</b>		

Where CFB= Control Flat bread ;HFB = Hydrocolloid added flat bread with (Guar gum);Ambient =(20°C,50%RH); Accelerated (38°C,75-80%RH).

**C.D(p<0.05)** Sample type : (S) = 0.005  
 Condition : (C) = 0.005  
 Days : (D) = 0.008  
 S × C = 0.010  
 S × D = 0.013  
 D × C = 0.013  
 S × D × C = 0.016

**Table 4.76: Effect of storage conditions and packaging material on gumminess of low-gluten flat bread**

Storage Days	CFB			HFB)			Overall Mean	Factor
	Ambient	Accelerated	Sub mean	Ambient	Accelerated	Sub mean		
0	5.94	5.94	<b>5.94</b>	5.64	5.64	<b>5.64</b>	<b>5.79</b>	Amb=6.17 Acc=6.29
2	6.02	6.12	<b>6.07</b>	5.73	5.82	<b>5.77</b>	<b>5.92</b>	
4	6.16	6.31	<b>6.23</b>	5.88	5.90	<b>5.89</b>	<b>6.06</b>	
6	6.45	6.58	<b>6.51</b>	6.04	6.25	<b>6.14</b>	<b>6.33</b>	
8	6.69	6.83	<b>6.76</b>	6.27	6.49	<b>6.38</b>	<b>6.57</b>	
10	6.86	7.01	<b>6.93</b>	6.36	6.66	<b>6.51</b>	<b>6.72</b>	
<b>Mean</b>	<b>6.35</b>	<b>6.46</b>	<b>6.40</b>	<b>5.98</b>	<b>6.13</b>	<b>6.05</b>		

Where CFB= Control Flat bread ;HFB = Hydrocolloid added flat bread with (Guar gum);Ambient =(20°C,50%RH); Accelerated (38°C,75-80%RH).

**C.D (p<0.05)** Sample type : (S) = 0.009  
 Condition : (C) = 0.009  
 Days : (D) = 0.016  
 S × C = 0.013  
 S× D = 0.023  
 D ×C = 0.023  
 S ×D×C = 0.033

**Table 4.77: Effect of storage conditions and packaging material on chewiness of low-gluten flat bread**

Storage Days	CFB			(HFB)			Overall Mean	Factor
	Ambient	Accelerated	Sub mean	Ambient	Accelerated	Sub mean		
0	5.22	5.22	5.22	4.90	4.90	<b>4.90</b>	<b>5.06</b>	Amb=5.23 Acc=5.28
2	5.23	5.26	5.24	4.92	4.94	<b>4.93</b>	<b>5.08</b>	
4	5.29	5.36	5.32	4.99	4.95	<b>4.97</b>	<b>5.14</b>	
6	5.54	5.52	5.53	5.07	5.18	<b>5.12</b>	<b>5.32</b>	
8	5.68	5.66	5.67	5.19	5.32	<b>5.25</b>	<b>5.46</b>	
10	5.69	5.74	5.71	5.15	5.39	<b>5.27</b>	<b>5.49</b>	
Mean	<b>5.44</b>	<b>5.46</b>	<b>5.44</b>	<b>5.03</b>	<b>5.10</b>	<b>5.07</b>		

Where CFB= Control Flat bread ;HFB = Hydrocolloid added flat bread with (Guar gum); Ambient =(20°C,50%RH); Accelerated (38°C,75-80%RH).

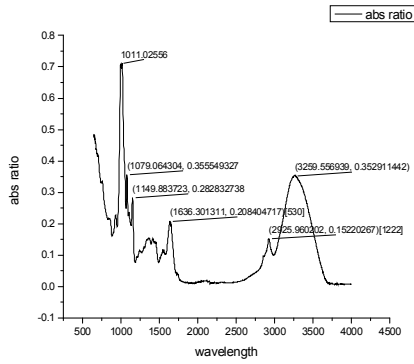
**C.D (p<0.05)** Sample type : (S) = 0.010  
 Condition : (C) = 0.010  
 Days : (D) = 0.017  
 S × C = 0.014  
 S × D = 0.024  
 D × C = 0.024  
 S × D × C = 0.034

#### **4.4.9 Degree of staling using FT-IR**

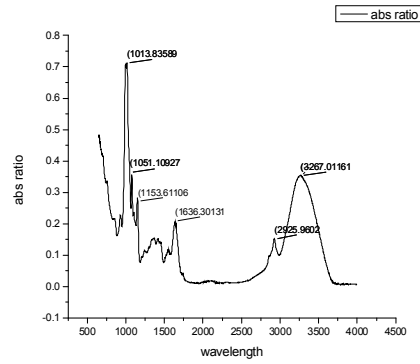
FT-IR spectrum of starch is reported to be sensitive to changes in structure at molecular level (short-range order), such as starch chain conformation, crystallinity and retrogradation (Bian and Chung, 2016). FT-IR spectra of control flat bread (CFB) and hydrocolloid incorporated flat bread (HFB) during storage were examined under two different storage conditions ambient and accelerated. The abundance of water (OH stretching vibration) in CFB and HFB were observed using FTIR spectra between 3600 and 3000  $\text{cm}^{-1}$ , while a broad envelope at 1200–800  $\text{cm}^{-1}$  was assigned to the polysaccharides bands to observe the change in intensity of functional group due to the polymeric interactions by hydrocolloids (Sivam *et al.*, 2012). It was observed that with increase in storage period from 0 to 10<sup>th</sup> day, the migration of water was assumed to occur as bread lose its stability or tend to degrade. The crumb of CFB was more dried compared to HFB. Further it was also observed that the staling rate was lower in HFB bread stored at accelerated temperature as compared to ambient one as shown in Fig (4.23).

#### **4.4.10 Free fatty acid (FFA)**

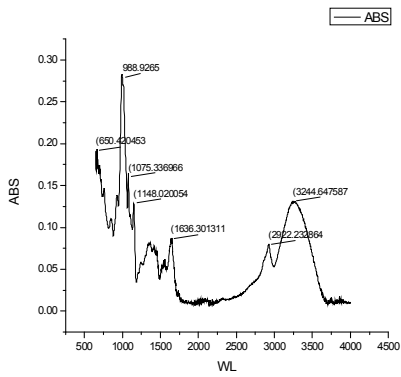
Free fatty acids (FFA) of control flat bread (CFB) and hydrocolloid incorporated flat bread (HFB) were found to increase non-significantly ( $p \leq 0.05$ ) with increase in the storage period (Table 4.78). Control flat bread stored under accelerated conditions showed more increase in FFA than those stored under ambient conditions. FFA increased from 0.230 to 0.350% and 0.180 to 0.260% in CFB and HFB samples, respectively stored under ambient conditions. However, under accelerated conditions FFA increased from 0.230 to 0.370 % in CFB and from 0.180 to 0.310 in HFB for the storage period of 10 days.



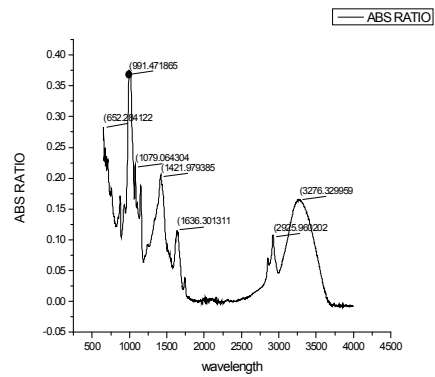
**Control at amb.cond**



**Control at acc.cond.**



**HFB at amb.cond**



**HFB at acc.cond.**

HFB = Hydrocolloid flat bread

**Fig. 4.23: Degree of staling using FT-IR under ambient and accelerated conditions**

**Table 4.78: Effect of storage conditions and packaging material on Free fatty acids of low-gluten flat bread**

CFB				(HFB)				
Storage Days	Ambient	Accelerated	Sub mean	Ambient	Accelerated	Sub mean	Overall Mean	Factor
0	0.230	0.230	<b>0.23</b>	0.180	0.180	<b>0.18</b>	<b>0.20</b>	Amb=0.25 Acc=0.28
2	0.260	0.280	<b>0.27</b>	0.190	0.220	<b>0.20</b>	<b>0.23</b>	
4	0.280	0.300	<b>0.29</b>	0.210	0.240	<b>0.22</b>	<b>0.25</b>	
6	0.300	0.320	<b>0.31</b>	0.220	0.260	<b>0.24</b>	<b>0.27</b>	
8	0.330	0.350	<b>0.34</b>	0.240	0.290	<b>0.26</b>	<b>0.30</b>	
10	0.350	0.370	<b>0.36</b>	0.260	0.310	<b>0.28</b>	<b>0.32</b>	
<b>Mean</b>	<b>0.29</b>	<b>0.30</b>	<b>0.30</b>	<b>0.21</b>	<b>0.25</b>	<b>0.23</b>		

Where CFB= Control Flat bread ;HFB = Hydrocolloid added flat bread with (Guar gum);Ambient =(20°C,50%RH); Accelerated (38°C,75-80%RH)

**C.D (p<0.05)** Sample type : (S) = 0.005  
 Condition : ( C) = 0.005  
 Days : (D) = 0.008  
 S × Cond = 0.007  
 S× D = 0.012  
 D×C = NS  
 S× D× C = 0.018

#### 4.4.11 Visible mould growth:

Table 4.79 illustrates the effect of storage conditions, packaging material and storage duration on visible mould growth of control flat bread (CFB) and hydrocolloid incorporated flat bread (HFB) under both storage conditions (ambient and accelerated). Results revealed that CFB packed in metalized polyester (Met-PE) showed mold growth on 6<sup>th</sup> day of storage whereas HFB showed mold growth on 8<sup>th</sup> day of storage under ambient storage conditions. Whereas under accelerated conditions, mold growth was visible on 4<sup>th</sup> days of storage in CFB, while as in HFB molds were visible on 6<sup>th</sup> day of storage respectively. However, studies could not be conducted beyond 8<sup>th</sup> days of storage as the product developed mold growth.

**Table 4.79: Effect of storage conditions and packaging material on Visible mould growth of low gluten flat bread**

CFB			HFB	
Storage Days	Ambient	Accelerated	Ambient	Accelerated
0	ND	ND	ND	ND
2	ND	ND	ND	ND
4	ND	visible	ND	ND
6	visible	visible	ND	Visible
8	visible	visible	visible	Visible
10	visible	visible	visible	Visible

Where CFB= Control Flat bread ; HFB = Hydrocolloid added flat bread with (Guar gum); Ambient =(20°C,50%RH); Accelerated (38°C,75-80%RH).

#### **4.4.12 Sensory evaluation**

Table 4.80, Table 4.81 shows the organoleptic evaluation scores of control flat bread (CFB) and hydrocolloid incorporated flat bread (HFB). Analysis of data revealed that organoleptic evaluation decreased significantly ( $p \leq 0.05$ ) under both storage conditions (ambient and accelerated). Overall acceptability scores in terms of colour, flavor, chewiness, hardness and staling was found significantly ( $p \leq 0.05$ ) higher in HFB as compared to CFB. With increase in storage period, the scores for all the organoleptic attributes decreased significantly. Overall acceptability scores of 4.0 for HFB was found higher than acceptability score of 3.8 for CFB under ambient conditions during the storage period of 8 days as mould growth was visible after 8 days of storage period in HFB bread whereas in case of CFB moulds were found visible on 6<sup>th</sup> day of storage period.

**Table 4.80: Effect of storage conditions and packaging material on sensory evaluation of control flat bread.**

Storage Days	Colour		Flavour		Chewiness		Hardness		Staling		O.A	
	Amb.	Acc.	Amb.	Acc.	Amb.	Acc.	Amb.	Acc.	Amb.	Acc.	Amb.	Acc.
0	4.5	4.5	4.3	4.3	4.2	4.2	4.5	4.5	4.2	4.2	4.3	4.3
2	4.5	4.1	4.3	4.0	4.2	3.9	4.5	4.1	4.2	4.2	4.2	4.0
4	4.3	4.0	4.0	3.9	4.0	3.7	4.1	4.0	4.1	4.1	4.0	3.9
6	4.1	3.9	3.9	3.7	3.7	3.6	4.0	3.9	4.0	4.0	3.8	3.7
Mean	4.3	4.1	4.1	3.9	4.0	3.8	4.2	4.1	4.1	4.1	4.0	3.9

**Table 4.81: Effect of storage conditions and packaging material on sensory evaluation of hydrocolloid incorporated low-gluten flat bread**

Storage Days	Colour		Flavour		Chewiness		Hardness		Staling		O.A	
	Amb.	Acc.	Amb.	Acc.	Amb.	Acc.	Amb.	Acc.	Amb.	Acc.	Amb.	Acc.
0	4.6	4.6	4.5	4.5	4.4	4.4	4.7	4.7	4.4	4.4	4.5	4.5
2	4.5	4.3	4.4	4.2	4.3	4.1	4.6	4.3	4.3	4.0	4.4	4.1
4	4.3	4.1	4.3	4.1	4.1	4.0	4.5	4.2	4.2	4.1	4.2	4.1
6	4.1	4.0	4.2	4.0	4.0	3.9	4.4	4.1	4.1	3.9	4.1	3.9
8	4.0	3.8	4.0	3.9	3.9	3.7	4.2	4.0	4.0	3.8	4.0	3.8
Mean	4.3	4.1	4.2	4.1	4.1	4.0	4.4	4.2	4.2	4.0	4.2	4.0

## Chapter-5

### DISCUSSION

The results of experiment obtained in the present investigation entitled “ Development of rice flour incorporated wheat based low gluten shelf stable kashmiri flat bread ” described in the preceding chapter has been discussed here with suitable reasoning.

#### **5.1 Experiment I: Evaluation of wheat and rice flour for different parameters**

##### **5.1.1 Physicochemical parameters of wheat and rice flour**

During the course of present study it was observed that refined wheat flour and rice flour showed a marked variation in their proximate composition for various nutritional and other parameters. A significant ( $p \leq 0.05$ ) difference was observed in the proximate composition of samples. Wheat flour possessed highest moisture content (11.12%), protein content (11.42%), ash (0.65%), crude fibre (1.32%) and crude fat (0.68%). while as highest carbohydrate content (79.84%) was found in rice flour. The high amount of moisture content in wheat flour may be attributed to higher protein content having higher affinity for moisture (Abrams *et al.*, 2014). The results obtained in term of the protein content of rice flour closely agreed with Jamal *et al.* (2016), Fari *et al.* (2011) and Han *et al.* (2011). Moreover, fiber content of the flour also influences the moisture content. Flour containing higher fiber content show higher moisture content and vice versa (Maneju *et al.*, 2011). The values of the ash content of rice flour are similar with the findings of Han *et al.* (2011), Thumrong chote *et al.* (2012) and Nura *et al.* (2011), who found a value ranging from 0.32 to 0.77%. Further, the highest carbohydrate content was observed in rice flour ( $79.84 \pm 1.57\%$ ) and lowest in wheat flour ( $74.81 \pm 1.12\%$ ). Since the carbohydrate content for flours was calculated by difference, the variation in carbohydrate content may be attributed to the differences in other constituents. The proximate composition of various

parameters recorded in the two flours were partially in accordance with the composition reported by Huttner *et al.* (2010). Wheat flour exhibited significantly ( $p<0.01$ ) higher reducing sugars ( $1.19\pm 0.19\%$ ), non-reducing sugars ( $4.14\pm 0.36\%$ ) and therefore higher total sugars ( $5.33\pm 0.43\%$ ) and rice flour exhibited significantly ( $p<0.01$ ) lower reducing sugars ( $0.26\pm 0.05\%$ ), non-reducing sugars ( $1.56\pm 0.13\%$ ) and therefore lower total sugars ( $1.82\pm 0.11\%$ ). Naik and Sekhon (2014) reported similar results for wheat flour, however, Amin *et al.* (2018) reported lower total sugars in rice flour as compared to our study. It was also observed that wet gluten (28.20%) was found only in wheat flour. This is similar with the findings of Kataria (2014) who found negligible wet gluten content in rice flour, soya bean flour, maize flour and sesame flour. Therefore, these flours are found suitable for celiac patient as they cannot tolerate gluten. Also rice flour is gluten-free with major storage proteins of glutelins (65–85%) while prolamins are present in smaller amount (Marco and Rosell, 2008).

Total starch was higher in rice flour ( $75.15\pm 1.30\%$ ) and lowest in wheat flour ( $68.92\pm 1.65\%$ ) because rice is rich in starch. Similar findings were reported by Amin *et al.* (2018) for rice flour and Naik and Sekhon (2014) for wheat flour. The amylose content of wheat flour ( $23.03\pm 1.17\%$ ) was significantly ( $p<0.01$ ) greater than rice flour ( $16.5\pm 1.10\%$ ), thus the amylopectin contents of wheat and rice flour were  $75.97\pm 2.56\%$  and  $83.41\pm 2.87\%$ , respectively. Amin *et al.* (2018) reported 17.11% amylose in rice flour and Itthivadhanapong and Sangnark (2016) reported 24.2% amylose in wheat flour which is consistent with the present study. whereas, resistant starch ( $4.154\pm 0.58\%$ ) was significantly ( $p<0.01$ ) higher in wheat flour. Similar findings were reported by Amin *et al.* (2018) in rice flour and Sterbova *et al.* (2016) in wheat flour. Falling number which indicates  $\alpha$ -amylase activity was significantly ( $p< 0.05$ ) higher in rice flour ( $550\pm 5$  sec) and lower in wheat flour ( $438\pm 4$  sec) Falling number indicates flour quality. More the falling number low will be the amylase activity and vice versa. According to AACC (2005) high falling number (above 300 s) indicates minimal enzyme activity and

sound quality of wheat flour. A low falling number (below 250 s) indicates substantial enzyme activity and sprout-damaged wheat or flour. Even after reconstitution, falling number of all flour samples was above 300, thus indicated minimal enzyme activity and sound quality of wheat flour (Kaushik *et al.*, 2015). Damaged starch (DS) is a man made component of wheat flour of significant importance as it alters rheological properties of dough and predicts end quality of baked products especially bread, pasta and biscuits. It is produced during milling when starch granules are mechanically ground to fine flour. It has been suggested that flour particle size, damaged starch and protein quality and quantity have effects on the baked products (Guttieri *et al.*, 2001). Damaged starch content of wheat flour (9.80%) was higher than that of rice flour. The reason for this could be higher grain hardness. A direct positive correlation is found in protein and ash content with the DS which has been reported by Barrera *et al.* (2007) and Keskin *et al.* (2012). The grain hardness strongly depends upon protein and ash contents and produces comparatively more damaged starch.,

### **5.1.2 Mineral profile of wheat and rice flour**

Mineral content of wheat and rice flour revealed that rice flour contained significantly ( $p < 0.01$ ) higher sulphur ( $66.60 \pm 2.20$  mg/100g) and higher phosphorous ( $148 \pm 2.40$  mg/100g) whereas, significantly ( $p < 0.01$ ) higher sodium ( $4.85 \pm 2.80$  mg/100g), calcium ( $18.12 \pm 1.80$  mg/100g), iron ( $2.15.00 \pm 0.10$  mg/100g) and zinc ( $2.92 \pm 0.89$  mg/100g) was reported in wheat flour. Similar findings were reported by Thomas *et al.* (2015).

### **5.1.3 Pasting properties of wheat and rice flour**

Pasting property is an index for predicting the ability of a food to form a paste when subjected to heat applications (Iwe *et al.*, 2016). Pasting time of wheat flour ( $7.02 \pm 0.02$  minutes) was significantly ( $p \leq 0.05$ ) higher than that of rice flour ( $6.73 \pm 0.01$  minutes). Higher pasting time of wheat flour could be attributed to high amylose content. The bonding force between amylose molecules are

strong due to the hydrogen bonds (Lin *et al.*, 2014) and the pasting of starch with high amylose content is difficult than that of starch with low amylose content, therefore, the pasting time of wheat flour was higher than that of rice flour. Pasting time is a measure of the cooking time. It indicates the minimum time required to cook flour and the results were in agreement with the findings of Blessing (2014) in wheat flour. Peak viscosity (PV) depicts the maximum viscosity attained by starch when heated in water, reflecting the water holding ability of starch granules (Shah *et al.*, 2016). PV of rice flour ( $2032.00 \pm 3.60$  cp) was significantly ( $p < 0.01$ ) higher than wheat flour ( $1675.00 \pm 2.44$  cp). This may be attributed to its greater water absorption capacity as well as swelling extent of starch granules (Wani *et al.*, 2012). At the same time, higher PT of wheat flour may be the possible reason for its lower PV (Chen *et al.*, 1998). Hold viscosity (HV) was significantly ( $p < 0.01$ ) higher in rice flour ( $1422.00 \pm 4.00$  cp) than wheat flour ( $1254.00 \pm 3.00$  cp). Higher hold viscosity of rice flour is due to its higher PV. Breakdown viscosity (BDV) is a measure of the degree of disintegration of swollen granules of starch by heating and physical agitation. Higher BDV indicates lesser capacity of the starch granules to withstand high temperature and shearing stress during cooking (Shah *et al.*, 2016). BDV of rice flour ( $419.00 \pm 1.80$  cp) was significantly ( $p < 0.01$ ) higher than wheat flour ( $385.00 \pm 1.51$  cp) which indicates its higher susceptibility to shear induced degradation during cooking. Final viscosity (FV) indicates the ability of flour to form a viscous paste after cooking and cooling. FV of wheat flour was found to be  $2585.00 \pm 2.60$  cp and that of rice flour was  $2098.00 \pm 3.92$  cp. This indicates that the FV of rice flour was significantly ( $p < 0.01$ ) higher than wheat flour possibly because of its swollen granules of starch which have a capacity to form viscous paste (Mir *et al.*, 2014). Setback viscosity (SBV) denotes the tendency of starchy substances to re-associate and retrograde upon cooling (Shah *et al.*, 2016). SBV of rice flour was found to be  $972.00 \pm 2.38$  cp than that of wheat flour  $808.00 \pm 1.76$  cp, which reflects its higher retrogradation tendency. Pasting temperature (PT) provides an indication of the minimum temperature at which the starch granules gelatinize by

forming a viscous paste (Shafi *et al.*, 2016). PT of rice flour ( $80.33 \pm 1.96^\circ\text{C}$ ) was significantly ( $p < 0.01$ ) lower than wheat flour ( $86.15 \pm 1.7^\circ\text{C}$ ). This indicates the less energy requirement of rice flour for initiating starch gelatinisation capacity of the starch granules to withstand high temperature and shearing stress during cooking (Shah *et al.*, 2016).

#### **5.1.4 Farinographic characteristics:**

Rheological information is valuable in product development. The farinograph gives a measure of dough consistency during its formation (Turabi *et al.*, 2008). Arrival time is a measurement of the rate at which the water is taken up by the flour, which is affected by the gluten of the flour as well as its damaged starch. The results showed longer arrival time in case of rice flour ( $8.70 \pm 0.02 \text{ min}$ ) in comparison to wheat flour ( $1.50 \pm 0.12$ ) this could be due to the presence of gluten in wheat flour which takes less time for hydration (William, 2001).

Degree of softening (DS) which is defined as the difference (in BU) between the line of the consistency and the medium line of the torque curve, 12 min after weakening begins.. Degree of softening is connected with its destruction, shortening of gluten tissues, dissolving of swollen gluten parts which lower the resistance to kneading (Zaidel *et al.*, 2008 and Karaoglu, 2011). Weaker flours tend to have higher values of degree of softening and it generally gives the rate of dough breakdown and the strength of flour. Rice flour showed significantly ( $p < 0.05$ ) higher values ( $55 \pm 2.23 \text{ min}$ ) for degree of softening than wheat flour ( $40 \pm 2.11$ ). The results were in agreement with previously conducted studies (Majzoobi *et al.* 2011; Muranga *et al.* 2010).

Water absorption is considered to be an important characteristic of flour. Rice flour showed significantly ( $p < 0.01$ ) higher water absorption capacity ( $62.3 \pm 2.41\%$ ) than wheat flour ( $60.2 \pm 2.30\%$ ). Higher water absorption is required for good bread characteristics which remain soft for a longer time. Naik and Sekhon (2010) reported a range of 48.66 - 62.12 g/100 g water absorption for

different wheat flours whereas, Curic *et al.* (2007) reported water absorption value of 60% for rice flour which is consistent with the present study. Dough development time (DDT) is the time from water addition to the flour until the dough reaches the point of the greatest torque

Rice flour showed significantly ( $p < 0.01$ ) higher values ( $10.0 \pm 1.19$  min) for dough development time and lower value was reported in wheat flour ( $3.80 \pm 1.12$  min). The longer development time was also noticed by Sivaramakrishnan *et al.* (2004). Stability values are usually indicators of flour strength and higher values represent stronger dough. This value, in general, gives some indication of the tolerance of the flour to mixing. Rice flour had minimum value of stability ( $1.78 \pm 0.23$  min) than wheat flour ( $4.8 \pm 1.16$  min). Strong gluten flour gives the highest stability value, thus wheat flour had the highest dough stability than rice flour (Nemeth *et al.*, 1994).

The mixing tolerance index which is a measure of resistance of dough to deformation was reported to be higher in wheat flour ( $60.20 \pm 3.12$  BU) than rice flour  $20.00 \pm 2.19$  BU. The lower values indicated higher tolerance to over mixing. This indicated that rice flour had the best tolerance for mixing and wheat flour the poorest Nemeth *et al.* (1994) in comparative study of Canadian, Australian and American wheats reported a range of 60-170 BU for mixing tolerance index.

## **5.2 Experiment No. 2: Process optimization for the development of rice flour incorporated wheat based flat bread**

### **5.2.1 Model fitting**

For all the dependent variables, significant ( $p < 0.05$ ) models with coefficient of determination ( $R^2 = 0.92-0.99$ ) were developed. Predicted  $R^2$  was found to be in reasonable agreement with adjusted  $R^2$  for all the models. Coefficient of variation, which depicts the accuracy and reproducibility of models, ranged from 0.06% to 4.25%. A highly desirable adequate precision range (17.73- 466.70) was observed in all the models, which indicates the adequacy of model discrimination.

Non-significant lack of fit was observed for all the models, which implies that all second order polynomial models correlated well with the measured data.

## **5.2.2 Effect of process parameters on physicochemical properties of low-gluten flat breads (LGFB)**

### **5.2.2.1 Texture profile analysis (TPA)**

#### **5.2.2.1.1 Hardness (H)**

Hardness, one of the primary characteristics contributing to the eating quality, is defined as the amount of force necessary for biting bread samples. Flat bread with lowest hardness is desirable. Hardness of low-gluten flat bread was found to be decreased with increase in the rice flour proportion. The amylose and amylopectin matrix, which contribute to overall bread texture, are primarily responsible for hardness (Schiraldi and Fessas, 2000). Further, bread hardness, according to Gomez *et al.* (2003), is caused by interactions between gluten and fibrous components. The addition of rice flour diluted the gluten content which is the possible reason for lowering the hardness of flat bread. Jan *et al.* (2021) also recorded that the rice flour incorporation decreased hardness of wheat based pretzel. Similarly, mixing and fermentation times had also negative effects on hardness of LGFB. Fermentation, in addition to producing the CO<sub>2</sub> gas that creates the porous structure, has been seen to have a similar role to mixing by stretching the dough around the bubbles, assisting in the development of the gluten matrix (Tlapale-Valdivia, *et al.*, 2010). As a result, longer mixing and fermentation times resulted in softer breads. The results are in concomitance with those reported by Ilowefah *et al.*, (2015) for brown rice bread.

#### **5.2.2.1.2 Springiness (SPR)**

Springiness is related to the height that the food covers during the time that elapses between the end of the first bite and the start of the second bite. It is the elastic recovery that occurs when the compressive force is removed (Sester, 1993). Higher springiness values are recommended because it is associated to the

freshness and elasticity of the bread (Cornejo and Rosell, 2015). Increase in springiness of LGFB with increase in rice flour percentage can be attributed to its dilution effect of gluten resulting in increasing crumb elasticity of bread. Also, increase in fermentation time increases the springiness of the bread due to increase in carbon dioxide production which results in higher specific volume hence enhancing the springiness of bread. Similar results have been reported by Chis *et al.* (2020) in gluten free muffins.

#### **5.2.2.1.3 Cohesiveness (COH)**

Cohesiveness is defined as the ratio of positive force during the second compression to that during the first compression Cohesiveness characterizes the extent to which a material can be deformed before it ruptures, reflecting the internal cohesion of the material. Cohesiveness of LGFB increased upon addition of rice flour which was desirable indicating the bolus formation rather than disintegrates during mastication (Cornejo and Rosell, 2015). Further, fermentation time increases the cohesiveness of LGFB which may be attributed to the ability of dough to trap and withstand the pressure of expanding carbon dioxide resulting in more soft and cohesive dough (Falade *et al.*, 2014). Similar results have been reported by Yue *et al.* (2019) in steamed bread.

#### **5.2.2.1.4 Gumminess (GUM)**

Gumminess is another texture parameter which is correlated with hardness and cohesiveness, being determined by hardness multiplied by cohesiveness (Sing *et al.* 2015) and is the energy required to disintegrate a semisolid food until it is ready to swallow. The decrease in gumminess of LGFB with increase in rice flour can be ascribed to the inability of dough to catch the gas which resulted in decrease in gumminess of bread (Plyer, 1988). The results are in accordance with the findings of Matos & Rosell (2012) for gluten free breads.

#### **5.2.2.1.5 Chewiness (CHEW)**

Chewiness is the quantity to stimulate the energy required for masticating a semi-solid sample to a steady-state for swallowing (Sang *et al.*, 2015). Chewiness showed proportional patterns with hardness and gumminess. Chewiness of LGFB decreased with increase in feed composition. Decrease in chewiness could be credited to the low amylose content in rice flour which decreases the capacity to entrap leavening gas possibly due to gluten dilution resulted in decreased chewiness (Puphet, 2009). Similar results have been reported by Kraithong, *et al* (2018).

#### **5.2.2.2 Flat bread parameters:**

##### **5.2.2.2.1 Width:**

The increase in rice flour incorporation resulted in a decrease in bread width, presumably due to the high particle size of rice flour, which adversely affected the width of flat bread (Bose and Shams-ud-Din, 2010). Similar results were found by Qadri *et al.* (2018) for brown rice flour incorporated wheat based crackers. Width of low-gluten flat bread increased with the increase in mixing time. The reason for this could be that during mixing, frictional forces convert specific mechanical energy into heat, which gets imparted to dough, increasing its elasticity and extensibility and thus enhancing the width of bread (Rao and Bhargavi, 2017). The width of low-gluten flat bread increased with increase in fermentation time, this could be ascribed to the fact that during fermentation, gluten absorbs more water, gas cells become more expandable, dough becomes more pliable and smooth, hence increasing the bread size by an increase in width (Cauvain and Young, 2001).

##### **5.2.2.2.2 Thickness**

Increase in thickness with the increase in rice flour addition may be due to the decrease in width (Islam *et al.*, 2012). Similar reports were recorded by Tiwari *et al.* (2011) for wheat based biscuits replaced with various proportions of

chickpea, kidney pea and pigeon pea flours. The possible reason for this increase could be due to the development of a three-dimensional protein network with the capacity to absorb gas, as well as the incorporation of air cells into dough, which changes aeration and rheology of dough resulting in an increase in low-gluten flat bread thickness (Chin & Campbell, 2005). Similar results were recorded by Kokawa *et al.* (2017) for white pan bread.

#### **5.2.2.2.3 Spread ratio**

Spread ratio is regarded as one of the most essential quality parameters of baked goods because it is associated with texture, bite, grain fineness and overall mouth feel of the product (Bose and Shams-ud-Din, 2010). Higher spread ratio is most preferable. The decrease in spread ratio with the increase in rice flour incorporation may be attributed to decrease in width and increase in the thickness of low-gluten flat bread. In addition, as the spread ratio decreases, the number of hydrophilic sites accessible to compete for the limited free water in dough increases. The number of hydrophilic sites increases because composite flour appears to form aggregates. Islam *et al.* (2012) also recorded reduction in spread ratio when wheat flour was replaced with brown rice flour. Spread ratio was increased with increase in fermentation time. This may be attributed to the fact that during fermentation, decrease in gluten network occurs which results in viscous flow properties of dough, thus making the dough more elastic and high in spread ratio (Hoseney and Rogers, 1994). Also, because starch interacts with other ingredients in the flour-water dough system, therefore, starch addition lowers the gluten quality which enhanced viscous-flow and resulted in a wider dough spread (Hoseney, 1998). Similar results were reported by Dogan *et al.* (2010).

#### **5.2.2.2.4 Weight**

Higher loaf weight has positive economic effects on bread at the retail end. With increase in rice flour composition weight of low-gluten flat bread was found to be increased. The reason for this could be most likely due to the higher water

holding capacity of rice flour than wheat flour hence enhancing the water absorption (Rosell *et al.*, 2001). Also the presence of hydroxyl groups allows more water interaction through hydrogen bonding thus increasing the level of hydration and eventually more loaf weight. The result is in line with the findings of Islam *et al.* (2012) who reported increase in loaf weight in composite flour.

#### **5.2.2.2.5 Volume index**

Volume index has a great importance in determining the quality of product as it is generally influenced by the quality of the ingredients used in the formulation of product (Ahmed and Abozed,2015). Flat bread with higher volume indices are considered most desirable. with increase in rice flour composition decrease in the volume index was observed. This decrease in volume index resulting from rice flour incorporation may be due to the combined effect of gluten dilution and mechanical disruption of gluten network structure by the rice particles Mohammad *et al.* (2012).The dilution of gluten results in poor gas retention and lower ability of the dough to enclose air, thus reducing volume index (Wongklom *et al.*, 2016). The same effect was reported by Masoodi *et al.* (2002) in cakes. Further, mixing time and fermentation time had the significant positive effect on the volume index. The reason for increase in volume index due to increase in mixing time could be due to the development of sufficiently formed gluten which has the ability of holding more carbon dioxide gas,resulting in greater volume in bread (Priyati *et al.*,2016).Similar results were reported by Sreirejeki *et al.* (2017)in modified cassava starch-wheat composite flour.

#### **5.2.2.2.6 Specific volume**

Specific volume is a quality indicator of bread that indicates dough expanding ability and oven spring (Giannou and Tzia, 2007). with the incorporation of rice flour, specific volume of low -gluten flat bread decreased significantly ( $p < 0.05$ ). According to Ragaei *et al.* (2011), partial replacement of wheat flour with grains including cellulose, barley and oat resulted in a decrease

in the volume of bread loaves. This might be supported by the fact that replacing wheat flour with rice flour causes gluten dilution, which affects the proper gluten matrix development throughout the mixing, fermentation and baking processes. Sankhon *et al.* (2013) found similar outcomes in wheat bread incorporated varying concentrations of locust bean flour.

#### **5.2.2.2.7 Puffiness**

Puffiness of LGFB was found to decrease with the addition of rice flour. This may be due to the inability of rice proteins to hold air cells and lack of gluten network thereby resulting in decreased puffiness (Islam *et al.*, 2012): similar results were reported by Qadri *et al.* (2018) who determined decrease in puffiness of wheat based crackers by addition of brown rice flour

#### **5.2.2.2.8 Oven Spring**

One of the quality characteristics in baking is oven spring. It refers to the dough's ability to absorb carbon dioxide and stretch. The oven spring showed a decreasing trend with increase in rice flour incorporation and increasing trend with increase in mixing and fermentation times. The decrease in oven spring with the rise in rice flour incorporation could be related to a reduction in gluten in the dough (Adeyeye *et al.*, 2019). Gluten's viscoelastic qualities help to retain carbon dioxide from dough fermentation, giving wheat flour bread a foam or fluffy structure and increasing bread volume. The mixing and fermentation times had significant positive effects on the oven spring of bread. This could be attributed due to good viscoelastic qualities that dough acquires under optimum mixing and fermentation conditions allowing it to expand in the oven (oven spring) and resulting in a bread with appropriate volume and gas cell structure (Kokawa *et al.*, 2017). The findings are in line with previous research (Hruskodva and Skvrnova, 2018).

#### **5.2.2.2.9 Yield**

Yield of the low-gluten flat bread got increased with increase in rice flour composition because of the higher water holding capacity of rice flour than wheat flour hence, enhancing the water absorption capacity which resulted in increase in bread yield (Rosell *et al.*, 2001). Further mixing and fermentation time also had positive significant effect on bread yield which could be attributed to the increase in elasticity of dough. It becomes expandable increasing bread volume and consequently enhancing the bread yield. Also, increase in baking temperature resulted in decrease in yield of bread due to significant decrease in moisture content of breads which results in for shrinkage of the bread hence decreasing the bread yield (Tesfaye, 2010). Similar results were revealed by Teshome *et al.* (2017) in gluten free biscuits.

#### **5.2.2.3 Instrumental color**

Color is the important physical characteristics of flat breads and is directly related to the acceptability of food products. Increase in lightness could be because of decreased protein content of the developed low-gluten flat bread, there by minimizing the possibility of Maillard reaction. More protein is associated with increase in Maillard reaction and thus formation of brown color (Gomez *et al.*, 2003). It can be predicted also that mixing time had a positive significant effect on the  $L^*$  value of low-gluten flat bread sample. The reason for this could be due to the change in gas cell sizes that occurs as a result of cell coalescence. Also, it could be revealed that  $L^*$  value of low-gluten flat bread gets inversely affected with baking temperature. This is expected due to the enhancement of rate of formation of brown pigments on increasing temperature Jan *et al.* (2021). Similarly, redness ( $a^*$ ) and yellowness ( $b^*$ ) values of low-gluten flat breads decreased, which is noticeable as rice flour tends to have brighter and whiter color than wheat flour. Similar findings have been observed by Chung *et al.* (2014).

#### **5.2.2.4 Overall acceptability**

Overall acceptability (OAA) determines the final acceptability of the product. OAA of the low-gluten flat bread (LGFB) increased with increase in rice flour incorporation. The reason for this could be due to the mild flavour of rice flour and higher  $L^*$  value of low-gluten flat bread. Depending on the perception of bread type, the colour of the bread is one of the most important aspects in sensory evaluation for customers (Matos and Rosell, 2012). The findings are consistent with the findings of Jan *et al.* (2021). The fermentation time also had positive significant effect on the OAA of the bread. Longer fermentation times were shown to be preferred for breads that were mixed for a short time Kokawa *et al.* (2017) and Jooyandeh (2009) found similar effects in Iranian lavash flat bread enriched with whey protein.

#### **5.2.3 Optimization**

The optimum processing conditions for development of low-gluten flat breads was obtained on the basis of applying desirability function method and the desirability value obtained was 0.91. The optimum predicted conditions for development of low-gluten flat breads were feed composition : wheat flour to rice flour ratio (48:52); mixing time (3.3min), fermentation time (70min) and baking temperature (282°C). The predicted values matched the obtained values well with a variation of less than or equal to 3.75% and thus showed excellent predicted patterns of the proposed models. The results therefore, confirmed the validity and adequacy of the models for predicting dependent variables.

#### **5.2.4 Farinographic studies of optimized blend**

The farinograph gives a measure of dough consistency during its formation. The farinographic studies of optimized rice-wheat blended flour revealed that arrival time was increased as compared to wheat flour which could be due to the incorporation of rice flour which takes more time. The optimal blend showed a significantly ( $p < 0.05$ ) lower softening degree in comparison to the wheat flour

due to dilution in gluten network (Mohammad *et al.*, 2012). Water absorption is considered to be an important characteristic of flour. Flour blend showed significantly ( $p < 0.05$ ) higher water absorption capacity ( $55.4 \pm 0.31\%$ ) due to the incorporation of rice flour. Higher water absorption is required for good bread characteristics which remain soft for a longer time. Naik and Sekhon (2010) reported a range of 48.66 - 62.12 g/100 g water absorption for different wheat flours.

Dough development time (DDT) is the time from water addition to the flour until the dough reaches the point of the greatest torque. Flour blend showed significantly ( $p < 0.05$ ) higher values for dough development time than wheat flour. During the mixing phase, water hydrates the flour components and the dough is developed. Since DDT in flour blend was observed to be higher than wheat flour indicating that flour blend needed longer time to hydrate all the compounds than wheat flour. Additionally, the increase in DDT of flour blend is due to the increase in water absorption of the dough (Zaidul *et al.*, 2004).

Stability values are usually indicators of flour strength and higher values represent stronger dough. This value, in general, gives some indication of the tolerance of the flour to mixing. Flour blend had minimum value of stability than wheat flour. Strong gluten flour gives the highest stability value, thus wheat flour had the highest tolerance to mixing. Lower dough development time and higher dough stability of wheat flour indicated good protein quality. Nemeth *et al.* (1994) reported dough stability 1.5 to 5.0 minutes in Canadian, Australian and American wheats. The mixing tolerance index which is a measure of resistance of dough to deformation was reported to be higher in wheat flour and lower in blended flour respectively. The lower values indicated higher tolerance to over mixing. This indicated that rice flour and flour blend had the best tolerance for mixing and wheat flour the poorest. Nemeth *et al.* (1994) in comparative study of Canadian, Australian and American wheat reported a range of 60-170 BU for mixing tolerance index.

### 5.2.5 Pasting properties of optimized blend

Pasting profile is primarily related to the swelling and rupturing of starch granules which demonstrates the wider range of viscosity parameters for different flour samples. Pasting temperature (PT) indicates the minimum temperature at which the starch granules gelatinize by forming a viscous paste (Nisar *et al.*, 2021). PT of rice-wheat flour blend was lower than wheat flour. Peak viscosity (PV) depicts the maximum viscosity acquired by starch during heating in water, reflecting the water holding ability of starch granules. PV of flour blend was significantly ( $p < 0.05$ ) higher than wheat flour. Rice flour had higher PV therefore its incorporation into the wheat flour resulted in increase its PV. It is also evident from the results of PT as PT was slightly higher in wheat flour, indicating its low PV. Hold viscosity (HV) was significantly ( $p < 0.05$ ) higher in flour blend than wheat flour. Higher HV of flour blend is due to its higher PV. Breakdown viscosity (BDV) is a measure of the degree of disintegration of swollen granules of starch by heating and physical agitation. Higher BDV indicates lesser capacity of the starch granules to withstand high temperature and shearing stress during cooking Gujral *et al.* (2003). BDV of flour blend was significantly ( $p < 0.05$ ) higher than wheat flour which indicates its higher susceptibility to shear induced degradation during cooking. Final viscosity (FV) depicts the tendency of flour suspension by forming a viscous paste after cooking and cooling. FV of flour blend was significantly ( $p < 0.05$ ) higher than wheat flour possibly because of its swollen granules of starch which have a capacity to form viscous paste. (Mir *et al.*, 2014). It is also indicated from the results of BDV as BDV was lower in wheat flour, depicting its low FV. Setback viscosity (SBV) denotes the tendency of starchy substances to re-associate and retrograde upon cooling.. This indicates that the SBV of flour blend was significantly ( $p < 0.05$ ) higher than wheat flour which reflects its higher retrogradation tendency. Pasting time reflects the time required to reach peak in viscosity and ease of cooking a particular sample. Pasting time in flour blend was found to be non-significantly ( $p > 0.05$ ) lower than

wheat flour. Similar observations were recorded by Gomez *et al.* (2014) in chickpea wheat composite flours.

### **5.2.6 Physicochemical properties of optimized low gluten flat bread (LGFB)**

The moisture content of flat bread ( $30.13 \pm 0.57\%$ ) was significantly ( $p < 0.05$ ) higher than both rice flour and wheat flour which is due to the incorporation of rice flour as wheat rice breads have higher percentage of water than wheat breads. A significantly ( $p < 0.05$ ) higher fat, fibre and ash contents, while lower protein content was recorded in developed LGFB with respect to wheat flour. The use of rice flour may have possibly resulted in a decrease in protein content. The addition of various ingredients to the recipe results in an increase in ash, fat and fibre in developed flat bread which is in line with the findings of Jan *et al.* (2021) for rice flour incorporated wheat based pretzels. Higher carbohydrate of flat bread was observed which may be due to the high starch content in rice flour. These findings are in concomitance with the findings recorded by Khoshgozaran-Abras *et al.* (2014) in brown rice incorporated wheat based flat bread. Total and non-reducing sugars were found to be increased while reducing sugars reduced significantly ( $p < 0.05$ ) after baking in LGFB with respect to wheat flour. Formation of maltose during the baking process is responsible for the rise in total sugar content of flat bread (Hussain *et al.*, 2019). Reducing sugars decreased due to the fermentation and baking steps as yeast utilizes the sugars in the fermentation process and chemical changes take place at higher temperatures during baking (Rajeswari *et al.*, 2018).

Further, amylose, amylopectin, total starch, resistant starch and damaged starch results showed that LGFB had more total starch compared to wheat flour, presumably due to the incorporation of rice flour, which is high in starch. The apparent amylose content and resistant starch contents of flat bread increased respectively, after the addition of rice flour. Baking causes the hydrolysis of  $\alpha$ -D-(1-6)-glycosidic bonds of amylopectin molecules, resulting in an increase in apparent amylose content and as a result, an increase in resistant starch content in

baked goods due to the retrogradation after cooling (Yadav, 2011). According to Robertson *et al.* (2005), a high resistant starch diet can significantly lower postprandial blood glucose and insulin reaction, as well as increase insulin sensitivity, which is believed to be helpful in delaying the postprandial rise in blood glucose in type-2 diabetic patients, as well as in the control and management of their condition. Therefore, the increase in resistant starch levels in flat bread is a desirable phenomenon from health point of view.

Damaged starch (DS) content of flour has a strong influence on its baking quality and showed a significant increase with increase in flour fineness (Barak *et al.*, 2014). with incorporation of rice flour in wheat dough the damaged starch content in blended dough was found to decrease which might be attributed to the dough with rice flour that creates a gel-like gelatinized starch hence degrading the gluten network of bread dough with the rice flour (Lorenz and Saunders 1978; Takano *et al.* 1980). Also a direct positive correlation is found in protein and ash content with the DS. Since with the addition of rice flour, the protein content was found to be decreased after bread making which correlates with the damaged starch content. Similar results has been reported by (Keskin *et al.*, 2012; Colombo *et al.*, 2008).

The wet and dry gluten contents of LGFB were found to be markedly lower with respect to wheat flour because of addition of rice flour. Rice flour is a gluten-free cereal and the major storage proteins consisted of glutelins (65–85%) while prolamins are present in smaller amount (Marco and Rosell, 2008).

### **5.2.7 Mineral profile of low-gluten flat breads**

Increase in mineral profile of the developed low gluten flat bread than rice and wheat flour was noticed. This increase may be attributed to the addition of ingredients and capacity of minerals to hold up well during baking (Hussain *et al.*, 2019). Amongst the macro minerals, sodium content was found in the highest concentration in developed low -gluten flat bread Among the micro minerals, iron

was significantly ( $p < 0.05$ ) higher in flat bread. Incorporation of rice flour significantly ( $p < 0.05$ ) increased the mineral content and thus improved the nutritional quality of the flat bread.

### **5.2.8 Texture Profile Analysis (TPA)**

The textural property is one of the major factors contributing to the eating quality of flat bread. Significant differences were observed in the textural parameters of the low-gluten flat bread. Hardness, cohesiveness, springiness, gumminess and chewiness of low-gluten flat breads were monitored from the texture profile analysis curve. It was found that rice flour incorporation had significant ( $p < 0.05$ ) effect on texture profile of low-gluten flat bread except gumminess. Hardness of low-gluten flat bread was decreased significantly ( $p < 0.05$ ) with the addition of rice flour incorporation, which is possibly due to the gluten dilution. Chevallier *et al.* (2000) revealed that the hardness is due to interactions between starch and protein through hydrogen bonding. Springiness of low-gluten flat bread increased significantly ( $p < 0.05$ ) upon increasing the addition of rice flour. It is related with a fresh and elastic product, hence high springiness values will be correlated with high quality bread (Matos and Rosell, 2012). With respect to cohesiveness, it was observed to increase significantly ( $p < 0.05$ ) with the increase in rice flour addition. Cohesiveness refers to how often a substance can be deformed until it ruptures and it reflects the material's internal cohesion. Bread with a high cohesiveness is preferred due to the formation of bolus rather than disintegrates during chewing, whereas bread with a low cohesiveness is more likely to crack or crumble (Jan *et al.*, 2019). Gumminess and chewiness of low-gluten flat bread was decreased upon increasing the addition of rice flour. Chewiness showed proportional patterns with hardness and gumminess. Chewiness of low-gluten bread decreased with increase in rice flour composition. Decrease in chewiness could be credited to the low amylose content in rice flour which decreases the capacity to entrap leavening gas possibly due to gluten

dilution resulted in decreased chewiness (Puphet, 2009). For gluten-free breads, Matos and Rosell (2012) found comparable results.

### **5.2.9 Sensory evaluation of optimized low-gluten flat bread.**

The sensory score in terms of flavour increased with the increase in rice flour proportion. Panelists rated the higher score for appearance ( $4.20\pm 0.21$ ) for low-gluten flat bread due to the formation of desired uniform light brown spots over the surface by baking. Color has an important role in the consumer's perception related to the acceptability of product. The LGFB bread received higher score for colour also which may be ascribed to incorporation of rice flour resulting in bright colour. The scores for flavour and texture varied significantly. Panelists rated lower score for flavour of low-gluten flat bread due to the addition of rice flour which has bland flavour. Further, texture ( $4.43\pm 0.51$ ) was rated higher score by the panelists possibly due to the higher starch content and lower crude fiber contents of rice, which decreased the hardness and increased the textural properties of flat bread. Further, mouthfeel was rated lower score by the panellists possibly due to the coarse cell structure of rice flour which gave a gritty texture. Chewability of LGFB received higher score by panellists as flat bread was found to be less chewy due to decrease in gluten content by rice flour. Overall acceptability, described as the average value of all the sensory characteristics Singh *et al.* (2019) indicated that 52% rice flour incorporated wheat based flat bread was found most feasible for the development of low-gluten flat bread with desired quality attributes and overall acceptability (OAA).

### **5.2.10 Flat bread Parameters**

Flat bread parameters of low gluten flat bread (LGFB) revealed that the width of LGFB bread made from rice and wheat flour blend significantly decreased whereas, the thickness of flat bread was increased significantly. Increase in thickness may be due to the decrease in width. The changes in width and thickness were reflected in spread ratio. Spread ratio decreased with the

addition of rice flour which could be possibly due to the high particle size of rice flour which resulted in lower spread ratio of flat bread (Singh *et al.*, 2003). Similar results were found by Islam *et al.* (2012). Weight of the LGFB was found to be increased due to higher water holding capacity of rice flour (Rosell *et al.*, 2001). Volume index and specific volume were observed to reduce with incorporation of rice flour, which could be ascribed to the combined effect of gluten dilution which inhibits the free expansion and resulted in decreased volume. (Wongklom *et al.*, 2016). Similar observations had been reported by (Ocheme *et al.*, 2010). Further puffiness and oven spring were also found to be decreased with incorporation of rice flour. The reason for this could be due to the inability of rice proteins to hold air cells and lack of gluten network there by reducing puffiness and oven spring in flat bread. Similar findings have been reported by (Qadri *et al.*, 2018). Further more, yield of LGFB was increased with increase in rice flour composition because of the higher water holding capacity of rice flour than wheat flour hence enhancing the water absorption capacity which resulted in increase in bread yield %. (Rosell *et al.*, 2001).

### **5.3 Experiment No. 3: To study the effect of hydrocolloids on the quality and storage stability of optimized low-gluten flat bread**

The optimized low-gluten flat bread developed through optimization of processing conditions, were incorporated with three different hydrocolloids SSL (sodium stearoyl-2-lactylate), GG (guar gum) and CMC (carboxymethyl cellulose) at a concentration of 0.3-0.9% and stored under ambient (20 to 25°C) conditions for 8 days. The hydrocolloid incorporated low- gluten flat breads were analyzed for below mentioned parameters:

#### **5.3.1 Proximate Composition**

The moisture content was observed to be increased with the addition of different hydrocolloids *viz.*, SSL, CMC and GG which may be due to the high

water-holding capacity of hydrocolloids however, highest increase was observed to be in CMC incorporated flat bread. This may be due to more hydroxyl groups of cellulose derivatives that cause more hydrogen links and have more water holding capacity (Shittu *et al.*, 2007). Moreover, flat bread was incorporated with three different hydrocolloid concentrations (0.3%, 0.6%, 0.9%) and the best results were obtained by adding 0.6% CMC followed by 0.6% GG and 0.6% SSL. This may be due to hydrocolloids that reduce the mobility of the water molecules. Increasing the concentration of hydrocolloids might transform free water to bound water (Barcenas and Rosell, 2005). Further, the moisture content was observed to be decreased significantly throughout the storage period which might be attributed to migration of moisture from crumb to crust and then to the outer atmosphere. These results are in accordance with findings of (Rehman and Mudassar 2003). The interactive effect of hydrocolloids, hydrocolloid concentration and storage days was found to be significant.

Crude fat content of the optimized low-gluten flat bread decreased significantly ( $p < 0.05$ ) with increase in the concentration of hydrocolloids from 0.3 to 0.9% in CMC and guar gum incorporated low-gluten flat bread except in SSL bread. The decrease in fat content with increase in concentration might be due to the polysaccharide nature of the hydrocolloids which is characterized by a high proportion of carbohydrates (China *et al.*, 2020). Similar trend was also observed by Zambrano *et al.* (2004). The results also revealed that SSL incorporated flat bread resulted in increase in crude fat with increase in hydrocolloid concentration from 0.3 to 0.9% which may be due to even distribution of lipids and generation of fatty acid-amylose complex which may remain in the starch granules (Ghanbari., *et al.*, 2008). Similar observations were observed by Pourafshar *et al.* (2018). Furthermore, with increase in storage days, the crude fat was found to decrease significantly which might be attributed due to the development of rancidity Leelavathi *et al.* (1984), as a result of the activation of lipase and lipoxidase enzymes, which split fat into fatty acid and glycerol. The interactive

effect of hydrocolloids, hydrocolloid concentration and storage days was found to be significant.

Crude fibre content of optimized low- gluten flat bread increased as concentration of hydrocolloids increased from 0.3 to 0.9% in CMC,GG and SSL incorporated flat breads. The incorporation of hydrocolloids enhanced the crude fibre content of low-gluten flat bread as hydrocolloids are composed of polysaccharides.(Rodge *et al.*, 2012). However more increase in Crude fibre was observed in CMC incorporated flat bread at 0.9% concentration because of cellulose derivates in CMC which cause more increase in fibre content (Ullah *et al.*, 2016). Moreover, with increase in storage days crude fibre content was observed to decrease possibly due to the degradation of bonds in polysaccharide chain of hemicellulose and other structural polysaccharide compounds. Similar observations were reported by Kumarasiri *et al.* (2018) in composite flour biscuits. Also, the interactive effect of hydrocolloids, hydrocolloid concentration and storage days was found to be non significant.

The crude protein was observed to decrease with the increase in concentrations of hydrocolloids *viz.*, SSL, CMC and GG, from 0.3 to 0.9% which might be due to the ability of polysaccharide to increase water absorption capacity resulting in decrease in crude protein (Murad *et al.* 2016). Further, the CMC incorporated bread at 0.9% concentration showed higher decrease in crude protein followed by GG and SSL incorporated breads. The reason for decrease in protein content might be attributed to concentration effect which occurs as a result of decrease in moisture content. These results are in agreement with Ho *et al.* (2014). However during storage, it was evident from the mean values for protein content that there was significant decrease in crude protein which might be attributed to the protease activity that is responsible for protein degradation during storage (Leelavathi *et al.*, 1984). Similar findings were reported by Ahmed *et al.* (2013). The interactive effect of hydrocolloids, hydrocolloid concentration and storage days was found to be significant.

Ash content in hydrocolloid incorporated low-gluten flat breads was found to get increased with increase in concentration from 0.3 to 0.9% in SSL, CMC and GG incorporated flat breads which might be due to the ability of additives especially hydrocolloids, which have mineral binding and mineral absorption properties (Shittu *et al.*, 2009). Ash content was also found significantly ( $P < 0.05$ ) higher in CMC incorporated bread at 0.9% concentration which might be due to the ability of CMC to retain more minerals during baking because it entraps more water. However, with increase in storage days non significant decrease in ash % was observed in all three hydrocolloids incorporated low-gluten flat breads. The results are in close similarity to the findings of Guarda *et al.* (2004).

Carbohydrate content of the low-gluten flat breads increased with increase in concentration of hydrocolloids from 0.3 to 0.9% in SSL, GG and CMC flat breads which might be accredited due to the polysaccharide nature of the gum which is characterized by a high proportion of carbohydrates (China *et al.*, 2020). The highest carbohydrate content was found in CMC incorporated flat bread at 0.9% concentration followed by GG and SSL. Since the carbohydrate content for flat breads was calculated by difference, the variation in carbohydrate content may be attributed to the differences in other constituents. Further more, carbohydrate content decreased with increase in storage days in low-gluten flat breads incorporated with hydrocolloids. The reason for this could be due to the gelatinisation of starch that decreases considerably with the increase in storage period (Giri *et al.*, 2021). The results were in close similarity with the work of Gujral and Pathak (2002).

### **5.3.2 Instrumental colour**

Colour is generally considered as the important quality parameter by which foods can be judged. In case of flat breads and other baked products, it is used as an indicator to evaluate the degree of browning reactions. Hunter colour values ( $L^*$ ,  $a^*$  and  $b^*$ ) for low-gluten free flat breads reveals that with the incorporation of hydrocolloids from 0.3 to 0.9% significant and concentration dependant

changes were observed in all the colour attributes of low gluten flat breads simultaneously. The increase in the values of lightness ( $L^*$ ) was noted in SSL, CMC and GG incorporated low gluten flat breads indicating a decrease in browning reactions with the addition of hydrocolloids. This can be attributed due to the long molecular chains in gum polysaccharides that hinder the interactions between amine groups of proteins and carbonyl groups of sugars thereby reducing Maillard reaction marginally (Hamdani *et al.*, 2020). Maximum lightness was observed in CMC incorporated flat bread followed by GG and SSL. This is in accordance with the results reported by Rosell *et al.*(2001) and Guarda *et al.* (2004). Further more, with increase in storage period  $L^*$  values decreased significantly ( $p \leq 0.05$ ) in all hydrocolloid incorporated low-gluten flat breads. This indicated the darkening of product with the passage of time. The results are in agreement with the study conducted by (Zamora and Hidalgo, 2005). It was also observed that non significant interaction was found between hydrocolloids, hydrocolloid concentration and storage days.

The redness ( $a^*$ ) and yellowness ( $b^*$ ) value of hydrocolloid incorporated low-gluten flat breads followed inverse relationship with respect to lightness. It was observed that with increase in concentration of hydrocolloids from 0.3 to 0.9% redness ( $a^*$ ) and yellowness ( $b^*$ ) was found to be reduced which could be possibly due to decrease in browning reactions occurring within the low gluten flat breads with the addition of hydrocolloids gum based polysaccharides (Hamdani *et al.*, 2020).The results are in agreement with values reported by Basman *et al.* (2008). Futher more guar gum (GG) incorporated bread at 0.9 % concentration had the highest yellowness followed by CMC and SSL. while as CMC incorporated bread at 0.9% concentration had highest redness followed by GG and CMC. The results are in agreements with the findings of Mandala *et al.* (2009). However, as the storage period increased from 0 to 8 days ( $a^*$ ) values increased,while as ( $b^*$ ) values decreased significantly ( $p \leq 0.05$ ). This implies darkening of all flat breads with storage which could be due to oxidation of lipids

and reactions of the resultant oxidized products with proteins thereby causing browning and darkening of breads during storage. Similar findings have been reported by (Zamora and Hidalgo, 2005). The decrease in yellowness ( $b^*$ ) of the bread can be linked to the degradation of carotenoids that caused a change in color (Limbo, Torri and Piergiovanni, 2007). The significant interaction was found between hydrocolloids, hydrocolloid concentration and storage days.

### **5.3.3 Texture Profile Analysis**

#### **5.3.3.1 Hardness**

The effect of hydrocolloids on textural properties of low-gluten flat breads showed significant ( $p < 0.05$ ) difference from each other. Hardness is the force required to compress the material by a given amount (Abdelghafor *et al.*, 2011). Hardness analysis revealed that all hydrocolloids reduced hardness and produced a softer breads. The decrease in the hardness values due to the addition of hydrocolloids can be attributed to the capacity of these hydrocolloids to absorb and retain more water in the dough system (Patil *et al.*, 2016). Results reveal that at mid-concentration of hydrocolloids i.e at 0.6% concentration, softer breads were observed as further addition caused a harder texture. This might be presumably due to increase in hydrocolloid concentration that transforms the free water to bound water. Bound water is not able to act as a plasticizer any more. This may cause the hardness in bread containing higher concentration of hydrocolloids. (Barcenas and Rosell, 2005). Further more, less hardness was noted in guar gum (GG) incorporated breads followed by SSL and CMC. This could be attributed due to the softening effect of guar gum that preferentially binds to starch avoiding the formation of spongy matrix and thus minimizing the rate to retrogradation (Shalini and Laxmi 2007). However, increasing trend of hardness was observed during storage period. The increase in hardness may be due to the effect of starch retrogradation and a poor extensible gluten network that lead to the hardening and staling in breads. These results are in accordance with

Arendt *et al.* (2008). It was also observed that there existed a significant interaction between hydrocolloids, hydrocolloid concentration and storage days.

### **5.3.3.2 Cohesiveness**

Cohesiveness characterizes the extent to which a material can be deformed before it ruptures, reflecting the internal cohesion of the material. Cohesiveness increased with the addition of hydrocolloids from 0.3 to 0.9% concentration in all hydrocolloid incorporated low-gluten flat breads i.e SSL, CMC and GG. Increase in cohesiveness in low- gluten flat breads had a positive effect since more cohesive crumbs are less susceptible to disintegration (Correa and Ferrero, 2013). Increase in cohesiveness of breads with increase in concentration of hydrocolloids may be attributed due to the increase in specific volume with internal structure resistance to high stress and strains resulted in more cohesive flat breads (Navickis *et al.* 1982). Cohesiveness was found significantly ( $P < 0.05$ ) highest in case of guar gum flat bread at 0.9% followed by CMC and SSL. Similar results were found by Esteller *et al.*, (2004) in baked goods. Further, decrease in cohesiveness was observed during storage period that might be due to loss of intermolecular attraction between ingredients that cause the crumbling of crumb and that is usually associated with the loss of water. These results are in alignment with the findings of Ballolli *et al.*, (2014). Also significant interaction between hydrocolloids, hydrocolloid concentration and storage days was observed.

### **5.3.3.3 Springiness**

It is the elastic recovery that occurs when the compressive force is removed (Sester, 1993). Higher springiness values are recommended because it is associated with the freshness and elasticity of the bread (Cornejo and Rosell, 2015). The springiness value of the product has a positive correlation with elasticity. Increase in concentrations of hydrocolloids resulted in more elastic bread structure (Mohammadi *et al.* (2014). Higher springiness was found in CMC incorporated low-gluten flat bread at 0.9% concentration followed by guar gum

and SSL. The reason for higher increase of springiness in CMC incorporated low-gluten flat bread might be due to Na CMC having extended polymer chains that makes the solubility of Na CMC in water and produce elastic hydrogel formation resulting in higher elastic pore walls hence more springiness. Similar findings were reported by Harsono *et al.* (2021). Moreover, it was observed that springiness of flat bread was decreased with increase in storage days. Decrease in springiness has been related to the loss of porous structure over storage period and the presence of denser matrix (Jauharah *et al.*, 2014). It was also observed that there existed a significant interaction between hydrocolloids, hydrocolloid concentration and storage days.

#### **5.3.3.4 Gumminess and chewiness**

Gumminess and chewiness are secondary parameters and are mostly dependent on hardness rather than on cohesiveness or springiness. Increase in the levels of hydrocolloid incorporation from 0.3 to 0.9% caused a decrease in gumminess and chewiness values of low gluten flat breads. Lowered hardness due to the addition of hydrocolloids results in lowered values for chewiness (Szczesniak, 1963). The decrease in gumminess and chewiness due to the addition of hydrocolloids can be attributed to ionic interactions that have been detected between charged hydrocolloids explaining the formation of hydrophilic complexes with proteins (Rosell *et al.*, 2007). Further more, lower gumminess and chewiness was observed in guar gum incorporated low- gluten flat breads followed by CMC and SSL which was found in parallel to hardness values. Similar results have been reported by (Patil and Arya, 2018) in gluten free flat bread. However increase in gumminess and chewiness was observed during storage, that might be due to the increase in hardness and staling of flatbread during storage. Increase in gumminess and chewiness can be attributed to the loss of water and breakage of gluten protein network during storage, which resulted in increase in gumminess and chewiness. These results are in accordance with the studies conducted by Xie *et al.* (2003), Moore *et al.* (2004). Also, significant

interaction was found between hydrocolloids, hydrocolloid concentration and storage days.

#### **5.3.4 Bread parameters**

##### **5.3.4.1 Spread ratio**

Spread ratio, calculated as a ratio of width to thickness, decreased with the incorporation of hydrocolloids (SSL, GG, CMC) from 0.3 to 0.9% concentration. The decrease in spread ratio might be due to large number of hydroxyl groups in the gum structure which binds with available water via hydrogen bonding. This ultimately leads to an increase in the water holding capacity of gums which results in insufficient water for hydration resulting in lesser spread ratio Kaur *et al.* (2015). Similar findings were reported by Devisetti *et al.* (2015). Higher spread ratio was observed in CMC followed by SSL and GG due to differences in water binding capacity of the hydrocolloids employed here. However non-significant decrease was observed in spread ratio of hydrocolloid incorporated low -gluten flat breads during storage period. Similar observations were recorded by Singh *et al.* (2003). Further more, interactive effect between hydrocolloids, hydrocolloid concentration and storage days was found to be significant.

##### **5.3.4.2 Width**

The hydrocolloids incorporation including SSL, GG and CMC had a decreasing effect on width of low-gluten flat bread. However, the greatest effect was contributed by CMC followed by SSL and GG. Similar findings were reported by Guarda *et al.* (2004). In addition, three different concentration (0.3%, 0.6% and 0.9%) of three different hydrocolloids were used to study the effect on width and the greatest decreasing effect was observed due to 0.9% CMC followed by 0.9% SSL and 0.9% GG which may be due to increased the viscosity of dough at higher levels of CMC The flow of the dough particularly depended on the viscosity, greater the viscosity, lesser the spread and hence lesser will be the width. Similar findings have been reported by Giuberti *et al.* (2018). Moreover,

the width of hydrocolloid incorporated low gluten flat breads was decreased non significantly.

#### **5.3.4.2 Thickness**

The thickness of the low -gluten flat breads was increased significantly with the addition of hydrocolloids *viz.*(SSL, GG and CMC). Increase in thickness might be attributed due to decrease in width which is also reflected in spread ratio. Further more, with increase in concentration of hydrocolloids from (0.3 to 0.9%) thickness of flat bread was increased which might be attributed due to increase in viscoelastic properties of dough resulting in higher thickness. In addition to this, higher thickness was exhibited by CMC incorporated bread at 0.9% concentration due to the improvement in the effects of cellulose derivatives that are more comparative to natural hydrocolloids and having more water holding capacity because of more hydroxyl groups in cellulose derivatives (Bell, 1990; Guarda *et al.*, 2004). Similar results were observed by Rajesh *et al.* (2015). However, thickness of low -gluten flat breads was observed to get decreased with increase in storage period. This decrease in thickness could be due to high moisture loss during storage. Similar results were found by Sultana *et al.* (2014). The interactive effect between hydrocolloids, hydrocolloid concentration and storage days was also found to be significant.

#### **5.3.5 Volume index**

Volume index is an indicator of bread, cookie and cakes volume. Volume index is of importance in irregular shaped products likes cakes, breads (Kohajdova *et al.*, 2013). With hydrocolloid addition (SSL, GG, CMC) from 0.3 to 0.9% concentration volume index increased significantly in SSL,GG and CMC incorporated low-gluten flat breads due to increase in porosity of batter which results in higher volume. (Miller and Hosene, 1993). Moreover with increase in storage days, non significant decrease in volume index was observed in hydrocolloid incorporated low-gluten flat breads. The interactive effect between

hydrocolloids, hydrocolloid concentration and storage days was found to be non significant.

#### **5.3.5.1 Weight**

The incorporation of hydrocolloids (SSL, GG, CMC) from 0.3 to 0.9% concentration resulted in increase in weight, which might be attributed to the addition of hydrocolloids which increases the water absorption capacity resulting in higher water retention in flat bread hence, contributing to better gluten development (Rodge *et al.*,2012). The observations are agreement with Moore *et al.* (2006). Higher weight was found in CMC incorporated bread at 0.9% concentration followed by GG and SSL hydroxyl groups in CMC which have more water retention capacity. According to the research by (Sidhu and Bawa 2000), “the addition of CMC 0.1-0.5% was able to have a significant effect on the water absorption rate of bread dough.” However non-significant decrease was observed in weight of hydrocolloid incorporated low-gluten flat breads during storage period. Further more,interactive effect between hydrocolloids, hydrocolloid concentration and storage days was also found to be significant.

#### **5.3.5.2 Specific volume**

The specific volume of the low –gluten flat breads increased significantly with the addition of hydrocolloids *viz.*(SSL, GG and CMC). Increase in specific volume might be attributed to increased stability of the dough system during proofing (Guarda *et al.* 2004).As a result, additional strength was conferred to the gas cells of the dough, thereby increasing higher bread volume (Gomez *et al.*, 2004). Further more, with increase in concentration of hydrocolloids from (0.3 to 0.9%) specific volume of flat bread was increased and was found higher at 0.9% concentration in CMC added flat bread, which could be possibly due to increase in elasticity and extensibility of the dough hence enhancing the ability of dough to trap gas resulting in higher volume. Similar results were observed by Sidhu and Bawa (2000). Moreover specific volume of low-gluten flat breads decreased

significantly with increase in storage period which might be attributed to disproportionation of gas cells and loss of coalescence in dough (Kokelaar and Prins, 1995). Similar results were found by Mezaize *et al.* (2010). The interactive effect between hydrocolloids, hydrocolloid concentration and storage days was also found to be significant.

#### **5.3.5.3 Oven spring**

One of the quality characteristics in baking is oven spring. It refers to the dough's ability to absorb carbon dioxide and stretch. With the incorporation of hydrocolloids (SSL, GG, CMC) from (0.3 to 0.9%) concentration. The increase in oven spring was observed which might be attributed to the presence of hydrophilic side chains in hydrocolloids that create an inner molecular mobility to produce elastic micro-gels which surrounds air micelles leading to gas expansion in oven (Grover, 1982). Maximum oven spring was found in CMC incorporated bread at 0.9% concentration followed by GG and SSL, which could be due to the improving effects of cellulose derivatives allowing stronger interactions when submitted to high temperatures, thereby increasing gas retention or oven spring during baking. (Guarda *et al.*, 2004, Rosell *et al.*, 2001). Similar results were observed by other authors (Bárceñas and Rosell, 2005). Moreover the oven spring of low-gluten flat breads decreased significantly with increase in storage period which might be attributed to decrease in viscoelastic properties of dough resulting in low expansion. (Sharadanant and Khan, 2003). Further the interactive effect between hydrocolloids, hydrocolloid concentration and storage days was also found to be significant.

#### **5.3.5.4 Puffiness**

The puffiness of the low - gluten flat breads was decreased significantly with the addition of hydrocolloids *viz.* (SSL, GG and CMC) from (0.3 to 0.9%) concentration. The decrease in puffiness might be attributed to formation of rigid dough with addition of hydrocolloids, thus preventing air incorporation during

proofing hence decreasing the puffiness % in flat breads (Kohajdova *et al.*, 2013). In addition to this, higher puffiness was found in CMC incorporated bread at 0.9% concentration in contrast to GG and SSL. Since, CMC forms elastic micro-gels with hydrophilic side chains that are surrounded by air micelles (Grover, 1982), which prevent the coalescence of structure and thus, increases the puffiness of flatbreads. Similar results were observed by Maleki and MilaNi (2013). Moreover the puffiness of low gluten flat breads decreased significantly with increase in storage period which might be attributed to decrease in gas holding capacity, reducing volume hence decreasing puffiness. Further, the interactive effect between hydrocolloids, hydrocolloid concentration and storage days was also found to be significant.

#### **5.3.5.5 Yield**

The addition of hydrocolloids is reported to improve baking yield and reduce weight loss (Mohammadi *et al.*, 2014). With the incorporation of hydrocolloids (SSL, GG, CMC) from (0.3 to 0.9%) concentration, yield was increased which might be probably attributed to the hydrocolloid structure of selected gums which lead to retention of more moisture content in flat breads and allows more water interactions through hydrogen bonding (Guarda *et al.*, 2004). In addition to this, higher yield was observed in CMC incorporated bread at 0.9% concentration. Since, CMC tends to improve moisture absorption and prevents high baking loss and thus, increased yield with a linear increase in CMC concentration from 0.3 to 0.9% Mohammadi *et al.* (2014) also reported that bread yield increased from 146.80% to 151.90% as the CMC concentration increased from 5 to 15 g/k. Further, the yield of low gluten flat breads decreased significantly with increase in storage period which might be attributed to high moisture loss resulting in reduction of volume in bread hence declining bread yield. It was also observed that the interactive effect between hydrocolloids, hydrocolloid concentration and storage days was significant.

### **5.3.6 Degree of staling by FT-IR spectroscopy of low gluten hydrocolloid incorporated flat breads.**

Water-related variations such as water redistribution, have an influence on the measured spectra. The water-related variations, lying in the 3,000– 3,600  $\text{cm}^{-1}$  wavenumber interval, which corresponds to the O–H bond stretching vibration showed increase in unit absorbance with storage time which may also explain the effect of water mobility on water-starch protein interaction and therefore on staling. In addition, the second spectra band at 900–1150  $\text{cm}^{-1}$ , which corresponds to the “saccharides” group indicating progressive starch crystallization also showed increase in unit absorbance with storage time which may partially explain staling in low gluten -flat bread possibly due to starch retrogradation. This fact is due to the lower water content of breads in the storage period and probably due to the subsequent reorganisation of the water molecules into the protein-polysaccharide network (Schiraldi and Fessas, 2001), The results obtained are in agreement with Cocchi *et al.*, 2005) who observed an increase in absorbance unit with storage time in pan bread. Peaks at 1,047  $\text{cm}^{-1}$  are related to crystalline regions of starch (Karim *et al.* 2000). The band at \*1,151  $\text{cm}^{-1}$  is often used as an “internal correction standard peak” to make the measurements independent of uncontrollable factors. The ratio of peak intensities at 1,047 and 1,151  $\text{cm}^{-1}$ , which was assigned in literature Ottenhof *et al.* (2005) was used to monitor starch retrogradation. Additionally, the effect of hydrocolloids incorporations in decreasing moisture loss during storage was especially seen for breads incorporated with Guar gum at 0.6% concentration. (Fig 4.21). However, the addition of other hydrocolloids SSL and CMC did not affect the moisture content bread during storage. An explanation to that result was that guar gum performed best antistaling hydrocolloid (Shalini, 2009). Thus, addition of gum to the formulation may prevent moisture migration from crumb to crust resulting in decrease in moisture loss hence decreasing staling. Further the ratios of absorption peaks at 1047/1151 were found less in guar gum incorporated bread as compared

to other two hydrocolloids. which suggested that retrogradation was minimized with increase in storage days in guar gum incorporated flat breads as compared to SSL and CMC. The results showed decreased crystallinity values of all samples resulting in retardation of staling in terms of starch retrogradation. Similar results were reported by Sevenou *et al.* (2002).

### **5.3.7 Sensory Evaluation:**

Sensory evaluation is usually performed towards the end of the product development or formulation cycle. It is carried out to assess the reaction of judges towards the product. Significant differences ( $p < 0.05$ ) existed in all the sensory attributes measured for the low gluten flat breads incorporated with hydrocolloids. Incorporation of hydrocolloids *viz* (SSL, GG, CMC) from (0.3 to 0.9 %) concentration in low gluten flat breads significantly improved their sensory characteristics.

Panelists rated higher score for appearance, colour, hardness and staling and lower scores for flavour and texture for low - gluten hydrocolloid incorporated flat breads. The scores for appearance of low-gluten flat bread revealed that hydrocolloid addition of (guar gum at 0.6% concentration) resulted in maximum appreciation by the panelists followed by CMC and SSL, which could be possibly due to milky white bleached appearance of bread imparted by guar gum at mid concentrations that improved the acceptability of panellists in low-gluten flat breads. Positive effects of different hydrocolloid on bread sensory quality have been previously reported by (Kihlberg *et al.*, 2004). Futher, with in storage days appearance of hydrocolloid incorporated flat breads decreased significantly. The decrease in appearance scores can be attributed to moisture loss and colour deterioration during storage. However, non significant interaction was observed between hydrocolloids, hydrocolloid concentration and storage days.

### 5.3.8 Color

Colour is an important parameter concerning the consumer acceptability towards bread. As revealed from the means the hydrocolloids (SSL, GG and CMC) at (0.3,0.6 and 0.9%) concentrations showed significant variations in the color of low-gluten flat breads. Gill *et al* (2006) also reported that additives improved the color of chapattis. The highest color score was received in guar gum bread at mid concentration i.e at (0.6%) followed by CMC and SSL at similar concentration possibly due to the incorporation of guar gum which showed the highest scores with whitish color. These results are supported by the findings of Habib and Butt (2003), who observed a significant role for guar gum in the color of chapatti. Selomulyo and Zhou (2007) also confirmed the effects of CMC and guar gum on bread color. The decrease in color during storage may be due to the oxidation of fat, carotenoids and rancidity (Leelavathi *et al.*, 1984). However, colour scores decreased with increase in storage period, which can be attributed due to the oxidation of fat, carotenoids and rancidity (Leelavathi *et al.*, 1984). Further, the interaction between storage days, hydrocolloids and hydrocolloid concentration was significant with regard to sensory attributes.

### 5.3.9 Flavour

Perceptions of flavor are a sensations of taste and smell impressions. The taste is a sensation perceived by the tongue and influenced by the texture, flavor and composition of the foods. Results revealed that the hydrocolloids (SSL, GG and CMC) at (0.3, 0.6 and 0.9%) concentrations showed significant variations in the flavour of low-gluten flat breads. CMC containing flat bread at 0.6% concentration had the highest scores for flavour, followed by GG and SSL which can be ascribed due to cellulose derivatives which had natural flavor of bread. This hydrocolloid hides the little fermented flavor produced by the yeast. As the hydrocolloid concentration is low, it does not change the natural flavor of the bread and hence improves the flavour. The findings of the present investigation are in accordance with the results that were found by Rosell *et al.* (2001). Further,

with increase in storage days flavour scores of hydrocolloid incorporated flat breads decreased significantly. The negative effect of storage on flavour might be due to the increase in free fatty acid, alcoholic acidity or lipase activity. Moreover, the high moisture content during storage favoured hydrolytic rancidity (Leelavathi *et al.*, 1984). Further non significant interaction occurred between storage days, hydrocolloids and concentration.

#### **5.3.10 Texture:**

Texture belongs to organoleptic attribute which determines food palatability and has intense effects on consumer's approval of food products. All the hydrocolloids (SSL, GG and CMC) at (0.3, 0.6 and 0.9%) concentrations showed significant variations on texture of low gluten flat breads. The scores for texture for the low gluten flat bread revealed that addition of hydrocolloid (CMC at 0.6% concentration) resulted in maximum appreciation by the panellists followed by GG and SSL which can be attributed to the presence of cellulose derivatives that improve elasticity and a smooth texture in bread (Selomulyo and Zhou (2007). Further, with increase in storage days, texture scores of hydrocolloid incorporated flat breads decreased significantly and this deterioration in bread quality during storage was due to the transport of water from the hydrated gluten to the ice phase (Bot and De Bruijne, 2003). Further, the interaction between storage days, hydrocolloids and hydrocolloid concentration was significant with regard to sensory attributes.

#### **5.3.11 Hardness**

Hardness is mainly attributed to the amylose and amylopectin matrix which contributes to overall bread texture as bread hardness is due to interactions between gluten and fibrous materials. Results revealed that the hydrocolloids (SSL, GG and CMC) at (0.3,0.6 and 0.9%) concentrations showed significant variations in the hardness scores of low gluten flat breads. Guar gum containing flat bread at 0.6% concentration had the highest scores for hardness, followed by

CMC and SSL which can be credited due to softening effect of this hydrocolloid, inhibiting amylopectin retrogradation. Since guar gum preferentially binds to starch, hence avoiding the formation of spongy matrix therefore, decreasing the hardness in breads (Shalini and Laxmi 2007). Further, with increase in storage days, hardness scores of hydrocolloid incorporated flat breads decreased significantly. The negative effect of storage on hardness might be due change in texture to bread staling crumb hardening and loss in moisture. Similar results were found by Man *et al.* (2015). Moreover, significant interaction occurred between storage days, hydrocolloids and concentration.

### **5.3.12 Staling**

Staling is a chemical and physical process in bread and in other similar foods that reduces their palatability. Staling or firming causes baked goods to lose their freshness and initial eating qualities (Cauvain, 2015). It is an important parameter concerning the consumer acceptability towards bread. As revealed, the hydrocolloids (SSL, GG and CMC) at (0.3 ,0.6 and 0.9%) concentrations showed significant variations in the staling rate of low-gluten flat breads. The highest staling score was received in Guar gum bread at mid concentration i.e at (0.6%) followed by CMC and SSL at same concentration, possibly due to the interaction of gums interacting with the starch components of the bread through hydrogen bonding and thus left them less available for starch recrystallization. Hydrocolloids have been reported to give breads a longer shelf-life and thus the results were consistent with other findings (Dziezak 1991; Glicksman 1969; Maier *et al.* 1933). Further more, with increase in storage days staling rate increases resulting in loss of freshness, hence staling scores decreased. The decrease in staling scores during storage may be due to the mechanism of the hardening effect caused by moisture transfer from crumb to crust and the intrinsic hardening of the cell wall material that is associated with starch re-crystallization during storage (Guy *et al.*, 1983). Further, the interaction between storage days, hydrocolloids and hydrocolloid concentration was significant with regard to sensory attributes.

### 5.3.13 Overall acceptability (OA)

Overall acceptability includes many implications, which is important parameter in sensory evaluation. Overall acceptability is described as the average value of all the sensory characteristics (Singh *et al.*, 2019). Addition of hydrocolloids (SSI, GG and CMC) had significant effects on sensory attributes and overall acceptability of bread samples as they play a significant role in improving the color, taste, texture, flavour, appearance hence increasing the overall acceptability of low gluten hydrocolloid incorporated flat breads. Similar observations were reported by Kaur *et al.* (2015). However addition of guar gum at 0.6% concentration improved sensory properties of flat bread, giving higher scores for overall acceptability. With storage, scores for these sensory parameters decreased and were found to be highest at the start and the lower at the end. Since, OA was determined from other sensory attributes, the decrease in these sensory attributes may have led to a decrease in OA as well. At the end of the storage period, OA was recorded as 4.23 which indicated that the flat breads were very good even after 8 days of storage. Further, the interaction between storage days, hydrocolloids and hydrocolloid concentration was significant with regard to sensory attributes.

### 5.4 Experiment No. 4: **Effect of storage conditions and packaging material on the stability of the flat bread**

The low-gluten hydrocolloid incorporated flat breads were packed in Metalized polyester film (MPE) and stored under ambient (20 to 25°C,50%RH) and accelerated (38°C, 75-80%RH) conditions for a period of 10 days. The stored samples were analyzed for below mentioned parameters.

#### 5.4.1 Water activity

Water activity is an important factor in determining the physical (firmness) and changes of bread crumb during storage (Lazaridou *et al.*, 2007). Lower water activity has been associated with the increase in the firmness of breads.

Irrespective of the packaging material, the water activity content of hydrocolloid incorporated flat bread (HFB) was found to decrease significantly ( $p < 0.05$ ) under both storage conditions (ambient and accelerated) during the entire storage period. Water activity is positively correlated with moisture content where low water activity indicated low moisture content in flat breads. The decrease in water activity during storage period indicated rapid loss of moisture occurred within crumb resulting, in loss of bound water during storage (Cauvain and Young, 2011). Furthermore, water activity of HFB was higher than control flat bread (CFB). Which could be due to ability of hydrocolloids having high water holding capacity that confer stability to the products hence reducing firmness in breads (Collar *et al.*, 2001).

However, more decrease in water activity was observed in HFB stored under ambient conditions as compared to accelerated conditions which could be due to higher moisture ingress under accelerated storage condition maintained at higher RH thereby resulting in increase in water activity at accelerated conditions and decrease under ambient conditions. Sidhu *et al.* (1997) noticed a significant decrease was found in the water activity values during storage of Arabic flat bread. Moreover, significant interaction occurred between storage days, flat bread type and storage conditions.

#### **5.4.2 Moisture content**

Moisture content plays a critical role in determining the shelf stability of food products. Irrespective of the packaging material, the moisture content of hydrocolloid incorporated flat bread (HFB) was found to decrease significantly ( $p < 0.05$ ) under both storage conditions (ambient and accelerated) during the entire storage period. The decrease in moisture content during storage period can be attributed to the moisture migration from crumb to crust resulting in a dehydration of crumb with faster staling hence affecting the stability of bread. (Le-Bail *et al.*, 2009). Furthermore, moisture content of HFB was higher than control flat bread (CFB). This is attributed to the addition of hydrocolloids that led to significant

increase in moisture content due to the high water-holding capacity of hydrocolloids (Bárcenas & Rosell, 2005). However, more decrease in moisture content was observed in HFB stored under ambient conditions as compared to accelerated conditions which could be possibly due to storage of bread at lower temperatures that dries out quickly, accelerating the rate of staling studies (Gray & Bemiller, 2003). These findings agree with previous studies of Abu-Ghoush *et al.* (2007) which concluded that moisture content significantly decreased during storage. Further, the interaction between type of flat bread, storage days and storage condition was significant with regard to moisture content.

### **5.4.3 EMC and ERH**

Sorption properties can tell us a lot about the mechanical, shelf-life and other physical and chemical properties directly or indirectly. Sorption properties based on empirical models are used for monitoring temperature and moisture content of the stored product using various monitoring devices (Luthra *et al.*, 2019). The equilibrium moisture content (EMC) was observed to be higher in hydrocolloid incorporated flat bread (HFB) under ambient conditions which may be due to the addition of hydrocolloids which are having high water holding capacity in breads (Collar *et al.*, 2001) that led to significant increases in moisture content. Similar results were reported by Bárcenas and Rosell (2005). Further, the EMC was observed to be lower in control flat bread (CFB) under accelerated conditions due to the air temperature. Since at lower temperature, the kinetic energy of the water molecules was inadequate to free themselves from the sorption sites (Quirijns *et al.*, 2005). Therefore, the EMC value decreased with the increase in air temperature. Other studies reported similar results on starchy food products (Barreiro *et al.*, 2003; Rohvein *et al.*, 2004). Same trend was followed by equilibrium relative humidity (ERH). These isotherms showed that at a constant temperature, positive correlations exist between the EMC and ERH for all breads. The implication of the positive correlation could be explained by sigmoidal isotherms. Similar studies have been reported by Mousa *et al.* (2014).

#### 5.4.4 Instrumental color ( $L^*$ , $a^*$ and $b^*$ )

Color is an important attribute, because it is usually the first property the consumer observes (Wong and Lim, 2016). The color parameters  $L^*$ ,  $a^*$  and  $b^*$ , of hydrocolloid incorporated flat bread (HFB) was found to decrease significantly ( $p < 0.05$ ) under both storage conditions (ambient and accelerated) during the entire storage period. The decrease in  $L^*$  value during storage period can be attributed to decrease in the luminosity and progression of various oxidative and Maillard browning reactions during storage that might have reduced the brightness indicated the darkening of product with the passage of time. The results are in agreement with the study conducted by (Zamora and Hidalgo, 2005). However, the  $L^*$  value of HFB was found to be higher than the control bread (CFB) which can be attributed to the long molecular chains in gum polysaccharides that hinder the interactions between amine groups of proteins and carbonyl groups of sugars thereby reducing Maillard reaction marginally (Hamdani *et al.*, 2020). However, change in  $L^*$  value was higher in HFB under accelerated storage conditions compared to ambient. This might be due to the browning reactions taking place at faster rate during storage (Patade, 2013). Moreover, the residual air remaining in the package may cause oxidation that lead to color changes during storage. Further more, with the increase in storage period ( $a^*$ ) value was found to increase significantly ( $p < 0.05$ ) under both storage conditions (ambient and accelerated) during the entire storage. Increase in redness ( $a^*$ ) value suggests a darker color of low gluten flat breads due to reddish tints which might be associated with formation of browning and oxidative intermediates during storage (Zamora and Hidalgo, 2005). However, the  $a^*$  value of HFB was found to be lower than the control bread (CFB) which could be possibly due to decrease in browning reactions occurring within the low gluten flat breads with the addition of hydrocolloids gum based polysaccharides (Hamdani *et al.*, 2020). Further the changes in  $a^*$  values were higher in HFB under accelerated storage conditions which might be due to the decrease in luminosity resulting in various oxidative

reactions that cause faster browning at accelerated conditions. The results are in agreement with values reported by Basman *et al.* (2008).

The yellowness ( $b^*$ ) values decreased significantly ( $p < 0.05$ ) with the increase in storage period under both storage conditions (ambient and accelerated) during the entire storage. Decrease in yellowness ( $b^*$ ) value can be linked to the degradation of carotenoids that caused a change in color (Limbo, Torri and Piergiovanni, 2007). Further the ( $b^*$ ) value of HFB was found to be lower than the control bread which could be possibly due to increase in lightness values with the addition of hydrocolloids that inhibit the browning reactions with decrease in yellowness. The results may be justified on the basis of a decrease in the Maillard reaction upon the addition of gum polysaccharides (Damodaran, 2007). Further, more decrease in  $b^*$  value was observed in HFB under accelerated storage content due to the degradation of carotenoids that caused a change in color because carotenoids are prone to oxygen and light-thermal- dependent deterioration (Yusuf *et al.*, 2015). Moreover, the interaction between type of flat bread, storage days and storage condition was significant with regard  $L^*$ ,  $a^*$  and  $b^*$ .

#### **5.4.5 Starch**

The total starch exhibited a decreasing trend with increase in storage period. Irrespective of the packaging material, the decrease in starch during storage period can be attributed to the conversion of starch into sugars (Booth *et al.*, 1976; Osunsami *et al.*, 1976). Furthermore, the starch content of HFB was higher than control flat bread (CFB). The reason for this could be due to the addition of hydrocolloids that led to the retention of starch in both fresh and stored bread. Consequently, there was less decrease in the starch of the bread containing hydrocolloids compared to control bread. Since, hydrocolloids promote adhesive interactions among the gelatinized starch granules. It is assumed that these adhesive interactions can entrap them, keep them intact, hence resulting in more increase in starch content (Abdulmola *et al.*, 1996). However, more decrease in starch content was observed in HFB stored under accelerated conditions as

compared to ambient conditions which could be possibly due to hydrolysis of starch granules at accelerated conditions which breakdowns starch more rapidly than at ambient conditions hence, led to denaturation of starch granules. Similar results were observed by Oh *et al.* (2018) in rice starch.

#### **5.4.6 Resistant starch**

Resistant starch (RS) is an important contributor of glycemic response offered by carbohydrate-rich food; hence, lot of research is going on to enhance the RS content in processed foods due to its health benefits (Akerberg *et al.*, 1998). The resistant starch content (RS) of hydrocolloid incorporated flat bread (HFB) was found to increase significantly ( $p < 0.05$ ) under both storage conditions (ambient and accelerated) during the entire storage period. The increase in resistant starch content during storage period can be attributed to the retrogradation process in the course of which the linear flexible chains of amylose re-crystallize resulting in the formation of double helices, which are closely packed and stabilized by hydrogen bonds, thus are resistant to enzymatic degradation (Ashwar *et al.*, 2016).

Furthermore, RS of HFB was higher than control flat bread (CFB). This is attributed to the addition of hydrocolloids that led to significant increase in the viscosity of the system and form a coating over the surface of starch granules, which limits the hydrolysis of such granules due to the restricted diffusion of  $\alpha$ -amylase (Dartois *et al.*, 2010). Also hydrocolloids limit the mobility of water molecules and granular swelling which reduces the hydrolysis of starch due to tight intermolecular packing of starch polymer within the partially gelatinized starch granules hence are resistant to digestion (Yuris *et al.*, 2017). However, accelerated conditions resulted in more increase in RS as compared to ambient one which could be ascribed to amylose molecules that aggregate under the influence of prolonged high temperature and form double helical crystallites which are highly stable and resistant to enzyme action (Garcia *et al.*, 1999).

Further, the interaction between type of flat bread, storage days and storage condition was significant with regard to resistant starch.

#### **5.4.7 Spread Ratio**

Spread ratio is a physical attribute of baked product. It is an important characteristic for analysing the quality of product with the ones having higher value being more desirable (Pareyt *et al.*, 2009). With the advancement in storage time, the spread ratio content was decreased significantly ( $p < 0.05$ ) in low-gluten flat breads stored under ambient and accelerated conditions. Decrease in spread ratio with storage might be due to high moisture loss during storage. Similar results were found by Sultana *et al.* (2014). Since, spread is strongly correlated to the water absorption capacities. With storage water holding capacities decreases resulting in decreasing shrinkage of bread, thereby limiting spread (Vieira *et al.*, 2007). Furthermore, spread ratio of HFB was higher than control flat bread. According to Gurjal Mehta *et al.* (2003), gravitational flow, which is determined by the viscosity of dough, is one of the major factors that determine the spread ratio. Therefore, another reason for the increase in the spread ratio upon addition of hydrocolloids may be the change in the viscosity of flat breads. However more decrease in spread ratio was observed in HFB under accelerated storage content due to the higher shrinking effect which results in lesser spread. More over the non significant interaction was found between type of flat bread, storage days and storage conditions.

#### **5.4.8 Texture Profile Analysis**

##### **5.4.8.1 Hardness**

Hardness is the force required to compress the material by a given amount (Abdelghafor *et al.*, 2011). With increase in storage days hardness of low gluten flat breads was increased significantly ( $p < 0.05$ ) under both ambient and accelerated conditions. Increase in hardness with storage period might be credited to the mechanism of crumb-hardening during storage due to moisture

redistribution from crumb to crust and the intrinsic hardening of the cell wall material that is associated with starch re-crystallization during storage period (Guy *et al.*, 1983). However hardness of HFB was lower than the control flat bread. This can be attributed to the addition of hydrocolloids that have higher water retention capacity, since they preferentially bind to starch Collar *et al.* (2001) and consequently prevent starch-gluten interactions, inhibiting the amylopectin retrogradation, hence reducing the hardness. In addition to this, maximum hardness was observed in HFB stored under accelerated conditions due to higher staling rate. As the storage conditions increased to higher temperatures, the staling process was accelerated (Liu, 2005). Similar results have been reported by Sozer *et al.* (2011). Further, the significant interaction was found between type of flat bread, storage days and storage conditions.

#### **5.4.8.2 Springiness and Cohesiveness**

Springiness and Cohesiveness followed the similar trend during storage period. It was observed that with increase in storage days, springiness and cohesiveness of low gluten flat breads decreased under both storage conditions (ambient and accelerated). Decrease in springiness has been related to the loss of porous structure over storage period and the presence of denser matrix (Jauharah *et al.*, 2014). While as decrease in cohesiveness may result from increase in crystallinity in structure of fat over storage time (Glibowsk *et al.*, 201). However higher springiness and cohesiveness was found in HFB as compared to control flat bread. The reason for higher increase in springiness and cohesiveness was attributed to the increase in elasticity and specific volume resulting in more cohesive and springy breads. Also hydrocolloids could interfere either in the starch gluten interactions or in the formation of physical entanglements that increase the cohesiveness and springiness of breads. Moreover, the more decrease in springiness and cohesiveness was found under accelerated conditions that may be attributed to staling of bread at higher temperature that result in loss of intermolecular attraction between ingredients that further cause the crumbling of

bread hence is usually associated with the loss of water. These results are in alignment with the findings of Ballolli *et al.* (2014).

#### **5.4.8.3 Gumminess and chewiness**

Gumminess and chewiness are secondary parameters and are mostly dependent on hardness rather than on cohesiveness or springiness. With increase in storage period gumminess and chewiness increased significantly ( $p < 0.05$ ) under both ambient and accelerated conditions. Increase in gumminess and chewiness with storage period might be due to the increase in staling, which can be further attributed to the loss of water and breakage of gluten protein network during storage (Moore *et al.* (2004). Further, gumminess and chewiness of HFB was lower than the control flat bread. This can be attributed to the addition of hydrocolloids that decrease the gumminess and chewiness hydrocolloids due to the ionic interactions that have been detected between charged hydrocolloids explaining the formation of hydrophilic complexes with proteins occurring as a result of high water absorption (Rosell *et al.*, 2007). In addition to this, maximum gumminess and chewiness was observed in HFB stored under accelerated conditions due to higher staling rate. As the storage conditions increased to higher temperatures, the staling process was accelerated. The results reveal that more energy will be required to masticate a flat bread with the advancement of storage. Like that of hardness, gumminess and chewiness also depends mainly on storage temperature. The similar results have been reported by Sang *et al.* (2015). In addition to this, the significant interactions was found between type of flat bread, storage days and storage conditions with respect to texture parameters.

#### **5.4.8.4 Degree of staling by FT-IR**

FTIR analysis of control flat bread (CFB) and hydrocolloid incorporated flat bread (HFB) during storage were examined under two different storage conditions ambient and accelerated. The abundance of water (OH stretching vibration) in CFB and HFB were observed using FTIR spectra between 3600 and 3000  $\text{cm}^{-1}$ ,

while a broad envelope at 1200–800 cm<sup>-1</sup> was assigned to the polysaccharides bands to observe the change in intensity of functional group due to the polymeric interactions by hydrocolloids (Sivam *et al.* 2012). It was observed that with increase in storage period from 0 to 10<sup>th</sup> day, the migration of water was assumed to occur as bread lose its stability or tend to degrade. The arrangement of starch structure through starch retrogradation involves moisture, which affects the stability of breads during storage. This could be observed in low values of water activity (Fig 4.23) in bread on day 10 compared to day 0. CFB shows a decrease pattern of water distribution over the storage that is related to the weak absorption of OH stretching vibration at 3500 cm<sup>-1</sup> in comparison to HFB. The crumb of CFB was more dried compared to HFB. Since control flat bread (CFB) had significantly higher moisture loss and lower water activity than HFB. Also the loss of moisture for amylopectin retrogradation was suggested due to the availability of sufficient moisture required for the starch recrystallization. The moisture mobilized long polymer chain segments until these chains were gradually aggregated through intramolecular binding (Wang *et al.*, 2015). Without hydrocolloids, the moisture is more available for starch recrystallization. The broad OH vibration stretching of HFB might be related to its interaction with polymer ingredients and water molecules. These are reflected in smooth, compact and thick wall structure of HFB bread Fig.(4.22), which may indicate its strengthening effects in bread structure that able to immobilize the water molecules within the bread. Further, it was also observed that the staling rate was lower in HFB bread stored at accelerated temperature as compared to ambient one. Since storage temperature and staling rate have a negative dependence on each other (Colwell *et al.*, 1969). Therefore, we could speculate that the increase in temperature might retard the band narrowing and band intensity strengthening and delay the starch retrogradation during storage at high temperature. This indicated that amylopectin at low temperature retrograded more rapidly than that at high temperature. Similar results were reported by Ronda *et al.* (2011) who reported a slowdown of bread staling stored at temperature sufficiently below glass-

transition temperature *T<sub>g</sub>*. Manzocco *et al.* (2002) also reported that bread crystallinity was lowest under low temperature.

#### **5.4.8.5 Visible mould growth**

Bakery products are an important part of the balanced diet, however, like many other processed foods, bakery products are subjected to physical, chemical and microbiological spoilage (Saranraj and Geetha, 2012). However, microbiological spoilage is of major importance in determining the shelf life. With increase in storage period mould growth increased under both storage conditions (ambient and accelerated). However accelerated conditions resulted in higher increase of visible mould growth due to high humidity that facilitate the growth of microorganisms (Sian *et al.*, 1975). The shelf life of hydrocolloid incorporated bread (HFB) was more as compared to control flat bread due to metalized polyester (MeT-PE) packaging material having better moisture and oxygen barrier properties that extends the shelf life Amin *et al.* (2020). Also, HFB stored under ambient conditions was having a shelf life of 8 days compared to accelerated one which had only 6 days.

#### **5.4.8.6 Free fatty acid (FFA)**

With the advancement in storage time, the FFA content was increased significantly ( $p < 0.05$ ) in low-gluten flat breads stored under ambient and accelerated conditions but was well within the limit of 0.5% specified by FSSAI for foods.. Increase in FFA during storage is due to lipid hydrolysis or oxidation which results in cleavage of long chain fatty acid into small fatty acid moieties (Khan *et al.*, 2011). FFA of HFB was lower than the control flat bread (CFB). This can be attributed to the addition of hydrocolloids that reduce the interfacial surface tension at oil water interface that retard the lipase access to substrate, inhibiting lipid digestion and therefore decreasing the release of FFA (Dickinson *et al.*, 2018). Similar results were reported by Qin *et al.*, 2016). In addition to this, more increase in FFA content was observed in HFB stored under accelerated

conditions which could be possibly due to higher air and water ingress and high temperature that favour the biochemical reactions leading to FFA formation that increase FFA with increasing storage time (Lin *et al.*, 2012). Similar increasing trends of FFA content on storage for gluten-free extrudates have been reported by Jan *et al.* (2017). More over the significant interaction was found between type of flat bread, storage days and storage conditions.

#### **5.4.8.7 Sensory Evaluation**

Sensory studies of the product are important for estimating its acceptability and commercial significance. Colour is an important parameter concerning the consumer acceptability towards bread. Colour scores were also significantly affected during storage period under both ambient and accelerated conditions. Colour score decreased with increase in storage period may be due to the oxidation of fat, carotenoids and rancidity (Leelavathi *et al.*, 1984). However more colour score were observed to be decreased in accelerated storage conditions This decrease in color is due to the reducing sugars as these reducing sugars during baking get caramelized to produce more dark brown colour of flatbread at accelerated temperature. The results are similar to findings of Pylar (1988) and Latif (2005). Panelists rated higher scores for color in HFB as compared to control preferably due to the addition of guar gum which showed the highest scores with whitish color. Gill *et al.* (2006) also reported that additives improved the color in chapattis.

#### **5.4.8.8 Flavour**

Perceptions of flavor are a synthesis of taste and smell impressions. Flavour scores were also significantly affected during storage period under both ambient and accelerated conditions. Flavour score decreased with increase in storage period. The decrease in flavour scores with storage might be ascribed due to the be due to the increase in free fatty acid, alcoholic acidity or lipase activity. Moreover, the high moisture content during storage favoured hydrolytic rancidity (Leelavathi

*et al.*, 1984). Further, the flavour scores were observed to decrease more under accelerated conditions due to production of free fatty acids (FFA) by lipase or due to non-enzymatic reaction at high temperature (Camire *et al.*, 2007). In addition to this panelists rated higher scores for flavour in HFB as compared to control preferably due to the addition of hydrocolloid that hides the little fermented flavor produced by the yeast. As the hydrocolloid concentration is low, it does not change the natural flavor of the bread and hence improves the flavour. The findings of the present investigation are in accordance with the results that were found by Rosell *et al.* (2001).

#### **5.4.8.9 Chewiness**

Chewiness is the quantity to stimulate the energy required for masticating a semi-solid sample to a steady-state for swallowing (Sang *et al.*, 2015). Chewiness score decreased with increase in storage days under both ambient and accelerated conditions. Decrease in chewiness with storage days might be credited due to the decrease in water holding capacity with storage that result in staling of bread. However more decrease in chewiness scores were observed under accelerated conditions that might be attributed to the increase in bread firmness, which is caused by the recrystallization of starch and redistribution of water which ultimately reduces its foldability and chewiness in bread. Similar results were reported by Ribotta *et al.* (2003). Further more panelists rated higher scores for chewiness in HFB as compared to control which might be attributed towards higher moisture retention capacity of these hydrocolloids. Similar results were reported by (Barcenas and Rosell (2006), who studied the softening effects of hydrocolloids to hold available water in the system.

#### **5.4.8.10 Hardness**

Hardness scores were also significantly affected during storage period under both ambient and accelerated conditions. Hardness score decreased with increase in storage period, which might due to moisture redistribution from crumb to crust

and the intrinsic hardening of the cell wall material that is associated with starch re-crystallization during storage period. (Guy *et al.*, 1983). However more decrease in hardness scores was noticed at accelerated conditions which results in rapid loss of moisture resulting in staling of bread. Moreover panelists rated higher scores for hardness in HFB as compared to control preferably due to the addition hydrocolloids that have water retention capacity, since they preferentially bind to starch (Collar *et al.*, 2001) and consequently prevent starch-gluten interactions inhibiting the amylopectin retrogradation thereby reducing staling in breads.

#### **5.4.8.11 Staling**

Staling or firming causes baked goods to lose their freshness and initial eating qualities. (Cauvain, 2015).with increase in storage days staling scores decreased under ambient and accelerated conditions. However staling scores were more lower at accelerated conditions. which could be due to moisture transfer from crumb to crust and the intrinsic hardening of the cell wall material that is associated with starch re-crystallization during storage (Guy *et al.*, 1983). Moreover, panellists rated higher scores for staling in HFB as compared to control preferably due to possibly due to the interaction of gums interacting with the starch components of the bread through hydrogen bonding and thus left them less available for starch recrystallization as hydrocolloids have been reported to give breads a longer shelf-life. Maier *et al.* (1933).

#### **5.4.8.12 Overall acceptability**

Overall acceptability is an important parameter in sensory evaluation. Overall acceptability is described as the average value of all the sensory characteristics (Singh *et al.*, 2019). Over acceptability was decreased gradually with increase in storage period due to change in organoleptic properties. Overall acceptability decreased more in bread stored under accelerated conditions than that of ambient conditions because of increased hardness of bread which results in

retrogradation (Eleonora *et al.* (2007)). However overall acceptability of HFB received higher scores by panelists in comparison to control flat bread which might be due to retention of moisture content in flat breads. Also hydrocolloids play a significant role in improving the color, taste, texture, flavour, appearance hence increasing the overall acceptability of low gluten hydrocolloid incorporated flat breads. The results are in accordance with Indrani and Rao (2003), Sahalini and Laxmi (2007) and Gill *et al.* (2006).

## Chapter-6

### SUMMARY AND CONCLUSION

The present investigation was carried out to develop rice flour incorporated low-gluten wheat flour flat breads. The results obtained during the investigation have been briefly summarized below:

1. The raw materials wheat flour and rice flour were investigated for physicochemical characteristics. The results indicated that Wheat flour possessed highest moisture content, protein content, crude fibre and crude fat while as highest carbohydrate content was found in rice flour. The starch content of rice flour was noticeably higher than that of wheat flour, whereas total sugars were recorded higher in wheat flour. Falling number which indicates  $\alpha$ -amylase activity was significantly ( $p < 0.01$ ) higher in rice flour and lower in wheat. More the falling number, lower will be the amylase activity and vice versa.
2. Functional properties were also studied for two flours, the results of which indicated that rice flour had significantly ( $p < 0.01$ ) higher water absorption capacity ( $62.31 \pm 2.42\%$ ) and dough development time ( $10.0 \pm 1.67$  min) with lower dough stability ( $1.78 \pm 0.23$  min) and mixing tolerance index ( $20.00 \pm 2.19$  BU) than wheat flour.
3. Pasting properties of flours, determined by Rapid Visco Analyser, indicated that peak viscosity ( $2032.00 \pm 2.63$  cp) hold viscosity ( $1614.00 \pm 1.88$  cp) breakdown viscosity ( $491.00 \pm 0.89$  cp) final viscosity ( $2585.00 \pm 2.21$  cp) and setback viscosity ( $972.00 \pm 1.13$  cp) were significantly ( $p < 0.01$ ) higher in rice flour compared to wheat flour. However, pasting temperature of rice flour ( $80.33 \pm 1.96^\circ\text{C}$ ) was significantly ( $p < 0.01$ ) lower compared to wheat flour.
4. The process for the development of low -gluten flat breads was optimized using response surface methodology (RSM). The optimized process

conditions obtained were: wheat to rice flour ratio of 48:52, mixing time of 3.minutes, fermentation time of 70 minutes and baking temperature of 282°C.

5. The optimized rice-wheat blended flour was evaluated for farinographic characteristics and the results indicated that optimized blend had significantly higher water absorption ( $65.4\pm 1.31\%$ ), arrival time ( $3.50\pm 0.01$  min) and dough development time ( $5.51\pm 0.09$  min) with lower dough stability ( $2.13\pm 0.05$  min) and mixing tolerance index ( $52.84\pm 1.18$ ) than wheat flour.
6. Optimized low-gluten flat breads were investigated for physicochemical characteristics. The results of physicochemical characteristics indicated that rice flour incorporation significantly reduced crude protein ( $6.91\pm 1.19\%$ ) and significantly increased crude fat ( $2.12\pm 1.08\%$ ), crude fibre ( $2.46\pm 1.29\%$ ), ash ( $1.64\pm 0.06\%$ ), reducing sugars ( $0.64\pm 0.02\%$ ) and total sugars ( $6.07\pm 1.11\%$ ) in developed low-gluten rice - wheat flat breads.
7. Results of starch digestion profile revealed that low-gluten flat breads had significantly higher resistant starch ( $7.32\pm 1.74$ ) and amylose content ( $26.64\pm 2.38\%$ ) compared to wheat flour whereas, total starch ( $69.15\pm 2.84\%$ ) and damaged starch was significantly ( $p<0.05$ ) lower in low-gluten flat breads.
8. It was observed from the results of mineral analysis that sodium ( $112.40\pm 3.50$  mg/100g), zinc ( $3.20\pm 1.10$  mg/100g) and iron contents ( $4.60\pm 1.20$ mg/100g) were significantly higher in low gluten wheat flat breads upon incorporation of rice flour.
9. The results of bread parameters of developed low-gluten rice-wheat flatbreads revealed that spread ratio ( $15.0\pm 0.08$ ), volume index ( $1.54\pm 0.01$ cm), puffiness ( $23.85\pm 1.13\%$ ), oven spring ( $1.52\pm 0.02$ cm) and specific volume ( $3.95\pm 0.04$  cm<sup>3</sup>/g), were found to be lower, whereas,

weight ( $62.03 \pm 2.41$ g) and yield ( $135.53 \pm 3.63$ %) was found to be significantly higher upon incorporation of rice flour.

10. Texture analysis revealed that hardness ( $8.20 \pm 1.62$ N), chewiness ( $4.97 \pm 1.13$ N) and gumminess ( $5.48 \pm 1.20$ N) of low-gluten flat breads decreased whereas, springiness ( $0.85 \pm 0.09$ mm) and cohesiveness ( $0.71 \pm 0.06$ ) increased upon incorporation of rice flour.
11. Sensory evaluation revealed that appearance, color, texture, mouth feel and Overall acceptability were rated higher score by panelists whereas, as flavor and chewability rated lower scores, which indicated that 52% rice flour in wheat flour was found most feasible for development of low-gluten flat breads.
12. Optimized low-gluten flat bread was incorporated with three different hydrocolloids sodium stearoyl-2-lactylate) -(SSL), Guar gum-(GG) and carboxymethyl cellulose-(CMC), at 0.3%, 0.6% and 0.9% concentrations respectively. Results revealed that moisture content (34.01%), crude fibre (2.34%) and carbohydrate (53.74%) were found to be increased significantly ( $p < 0.01$ ) in CMC incorporated flat bread in comparison to GG and SSL incorporated flat breads.
13. Results further revealed that both guar gum and CMC were proven to be best for maintaining the quality and storage stability of low- gluten flat breads. However CMC exhibited utmost bread properties in comparison to GG and SSL whereas, GG was found best in decreasing the staling and there by maintaining the textural properties of low- gluten flat breads.
14. Structural properties of low-gluten hydrocolloid incorporated flat breads were elucidated by Fourier transform infrared spectroscopy (FT-IR). Degree of staling by FTIR studies revealed that guar gum flat bread showed best antistaling properties at 0.6% concentration in comparison to SSL and CMC. Further the ratios of absorption peaks at 1047/1151 were found less

in guar gum incorporated bread as compared to other two hydrocolloids, which suggested that retrogradation was minimized with increase in storage days in guar gum incorporated flat breads as compared to SSL and CMC.

15. Based on the organoleptic evaluation, breads incorporated with GG and CMC received highest score by panellists at 5 point scale and had better overall acceptability at 0.6% concentration. Flat breads prepared from GG proved significantly superior to those developed from SSL and CMC in appearance, colour, hardness and staling, whereas, flat breads prepared from CMC received higher mean scores for flavour and texture organoleptic attributes in comparison to SSL and CMC.
16. Storage studies were carried out for low-gluten hydrocolloid incorporated flat bread packed in metalized polyester (Met-PE) and stored under ambient and accelerated storage conditions for the period of 10 days. Moisture content, water activity, texture parameters, spread ratio and total starch of stored products decreased, while as free fatty acids and resistant starch increased under both storage conditions. However ambient conditions and metalized polyester (Met-PE) packaging was found most suitable for the packaging and safe storage of guar gum incorporated rice wheat flat bread.
17. The study confirmed that overall acceptability reduced during the storage period .However, guar gum incorporated low -gluten flat bread received higher score by panellists as compared to control flat bread.

## CONCLUSION

The study demonstrated that the incorporation of rice flour had better rheological and pasting properties than wheat flour suggesting its use in the development of low-gluten products or gluten free products with better characteristics. The optimized condition for the preparation of low-gluten rice - wheat flat breads revealed that replacing wheat flour with rice flour to a level of 52% (w/w) remarkably reduced the gluten content of developed flat breads suggesting its possible use for celiac patients and people with gluten intolerance. Mineral content was also revealed to be higher, which could be useful in terms of technological and nutritional benefits, as well as additional health benefits. Out of three different hydrocolloids used guar gum was shown to be the most effective in reducing staling, improving overall acceptability and shelf life stability of flat bread. Storage stability studies carried out for low-gluten flat breads showed that metalized polyester (Met-PE) under ambient conditions performed well in maintaining the quality of the product compared to accelerated conditions for 10 days and were organoleptically acceptable for 8 days. Therefore, it can be concluded that rice flour can be used as a wheat flour substitute due to lack of gluten, less sodium content and a high content of easily digestible carbohydrate.

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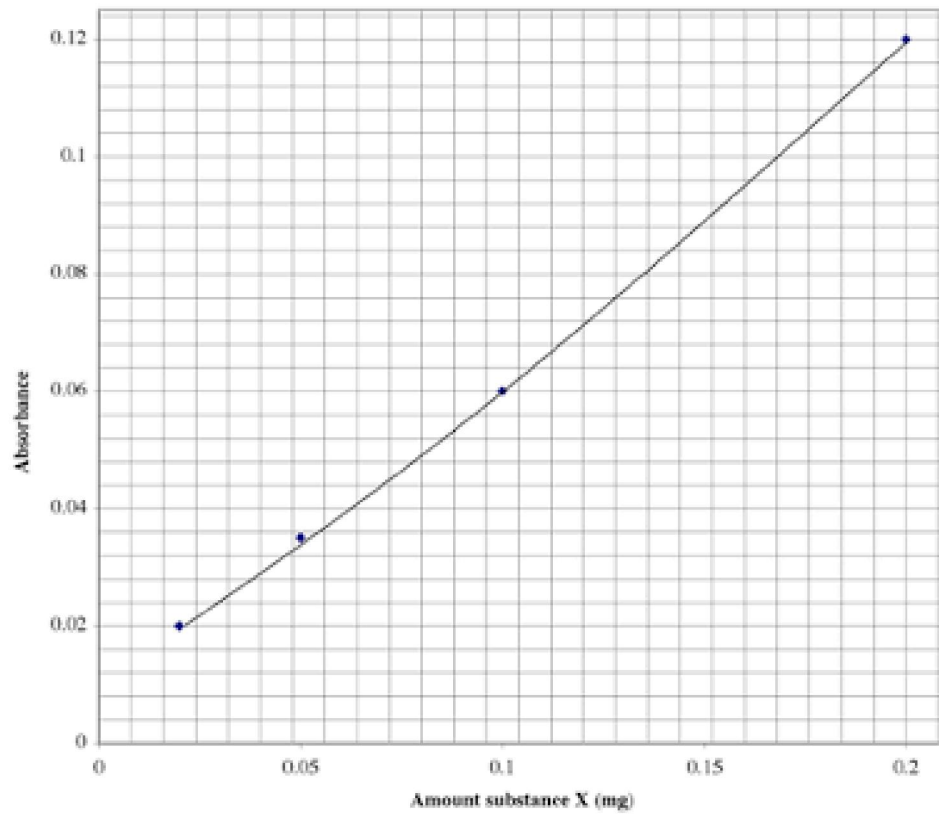
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**Standard curve - Total Sugars**



**Appendix-II**

**Sensory evaluation performa for optimized low gluten flat breads.**

Name of Panellist \_\_\_\_\_ Date \_\_\_\_\_

<b>S. No</b>	<b>Appearance</b>	<b>Colour</b>	<b>Texture</b>	<b>Flavour</b>	<b>Chewability</b>	<b>Mouth feel</b>	<b>Overall Acceptability</b>

- Excellent = 5
- Very good = 4
- Good = 3
- Fair = 2
- Poor = 1

**Signature of panellist**

**Appendix-III**

**Sensory evaluation performa for hydrocolloid incorporated low gluten flat breads .**

Name of Panellist \_\_\_\_\_ Date \_\_\_\_\_

<b>S. No</b>	<b>Appearance</b>	<b>Colour</b>	<b>Flavour</b>	<b>Texture</b>	<b>Hardness</b>	<b>Staling</b>	<b>Overall Acceptability</b>

- Excellent = 5
- Very good = 4
- Good = 3
- Fair = 2
- Poor = 1

**Signature of panellist**

**Sher-e-Kashmir**  
**University of Agricultural Sciences & Technology of Kashmir**  
**Faculty of Horticulture, Division of Food Science & Technology**

**CERTIFICATE**

Certified that all the corrections/amendments as suggested by External Examiner **Dr. Baljit Singh**, Professor/Principal Food Technologist, Department of Food Science and Technology, PAU Ludhiana during Viva-Voce examination held on 07-04-2022 have been incorporated in the manuscript entitled “**Development of rice flour incorporated wheat based low gluten shelf stable kashmiri flat bread**” submitted by **Ms. Qudsiya Ayaz (Regd. No. 2016-666-D)**.

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